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ABSTRACT

This document is the first of three volumes of the proceedings of an international seminar which focused on student misconceptions in science and mathematics as well as teaching strategies intended to deal with those misconceptions. An introduction to the volume explains the format of the conference and the organization of the sessions. It stresses the attention given to constructivism by the participants, as well as some of the problems associated with defining misconceptions and alternative frameworks. The remainder of the document contains 49 of the papers presented at the seminar, arranged in alphabetical order by senior author. These papers covered such topics as epistemology, research methodologies, metacognitive strategies, and the use of computers. Also included is a list of the conference participants. (TW)

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Proceedings of The
Second International Seminar
MISCONCEPTIONS AND EDUCATIONAL STRATEGIES
IN SCIENCE AND MATHEMATICS

July 26 - 29, 1987

CORNELL UNIVERSITY, ITHACA, NY, USA

Volume I



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PROCEEDINGS CONTENT BY VOLUME

VOLUME I: Overview of the Seminar; Epistemology; Research Methodologies; Metacognitive Strategies; Use of Computers; Roster of Participants

VOLUME II: Overview of the Seminar; Teacher Education; Teaching Strategies; Biology; Elementary Science; Roster of Participants

VOLUME III: Overview of the Seminar; Physics; Mathematics; Chemistry; Roster of Participants

* * * * *

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Second International Seminar
Misconceptions and Educational Strategies in
Science and Mathematics
July 26-29, 1987

Introduction

Our first seminar, held in 1983, showed that there was strong international interest in the general topic of student misconceptions in science and mathematics (see Helm and Novak, 1983). Advance announcements for our second seminar were more widely circulated, but the fact that over three times as many papers (177) were presented and more than three times as many participants (367) enrolled from 26 countries was clear indication of the great interest currently evidenced in the field. The proceedings are being printed in three volumes to accommodate all papers submitted. A roster of participants is included in each volume.

The format for the seminar followed the pattern of our first seminar: a wine and cheese informal reception on Sunday evening; morning and afternoon sessions for paper presentations and discussions; late afternoon plenary sessions to discuss "Issues of the Day"; and unscheduled evenings. There was the frustration for most participants of choosing between seven or eight simultaneous sessions, but papers were grouped by topics in an attempt to preserve some homogeneity of interests in each group. Papers are presented in the Proceedings in broad general categories similar to the groupings used in the seminar program, and in alphabetical order by senior author.

Meetings of the Psychology and Mathematics Education group were scheduled in Montreal, Canada just preceding our seminar and this facilitated participation by a number of math educators who might otherwise not have attended. In both our first seminar and again in 1987, there was a strong feeling that researchers in science education and in math education can benefit by greater interaction. Although parallel sessions devoted to science or math education research limited some of this interaction, plenary sessions and informal meetings offered some opportunities for much

needed cross-disciplinary dialogue. There was a general consensus that many of the issues and problems were common to both science and math education. In some areas of research, math education appears to more advanced than science education (e.g., concern for epistemology as it relates to instruction) and in other areas the reverse is true (e.g., the use of metacognitive tools to facilitate understanding). In the plenary session on physics and chemistry, similar concerns were evidenced in communication between sciences.

There remains the problem of definition of misconceptions, alternative frameworks, or whatever we choose to call these commonly observed patterns in faculty understanding evidenced in students, teachers and textbooks. There were more papers presented in this second seminar on how to deal with misconceptions than in the first; however, there was still heavy representation of papers dealing with the kind, number and tenacity of misconceptions and probably too few dealing with educational strategies to mollify or remove the deleterious effects of misconceptions or to limit teacher or text initiation of misconceptions.

More emphasis was evidenced on the importance of epistemology to improvement of science and math education. In general, there was strong endorsement of "constructivist" epistemology both for clarifying the nature of knowledge and knowledge production and as an underpinning for lesson planning and pedagogical practices. Of course, there was debate on the value of constructivist ideas and even some questioning of constructivist epistemology in contrast to empirical/positivist views on the nature of knowledge and knowing. A number of participants observed that we promulgate constructivist thinking for students, but too often we conduct teacher education programs that seek to give teachers fixed truths and methodologies, rather than recognize their need to reconceptualize subject matter and pedagogical strategies as they engage in the slow process of conceptual change.

Although concern for teacher education was better represented by papers in this seminar than in our first, there remained a common perception that new ideas and methodologies to improve teacher education, and much more field-based research in teacher education, are badly needed. As we launch this year at Cornell University a new science and mathematics teacher education program, with new faculty, we were especially sensitive to the concerns expressed. They represent an important challenge to us as we move ahead in the design, evaluation and analysis of our new teacher education initiatives.

In our closing plenary session, Ron Hoz expressed concern for the limited representation of papers dealing with the psychology of learning as it relates to science and mathematics education. This concern appears to be warranted in view of the fact that most psychologists interested in human learning have abandoned bankrupt ideas and methodologies of behavioral psychologists (e.g., B.F. Skinner), and are now developing and refining strategies for study of cognitive learning (e.g., James Greeno). The early work of Jean Piaget, George Kelly, David Ausubel and other cognitive psychologists is now entering the mainstream of the psychology of learning. These works have important relevance to the study of teaching and learning as related to misconceptions. A note of caution, however. Most of the behaviorist psychologists turned cognitive psychologists still operate methodologically as positivists. They hold constructivist views of learning (i.e., that learner's must construct their own new meanings based on their prior knowledge), but they adhere to rigidly positivist research strategies and often recommend teaching practices that ignore the teacher as a key player in constructivist-oriented teaching/learning. The "constructivist convert" psychologists were conspicuously absent from our participant roster. What is the message here?

There were more papers dealing with metacognitive tools. This may reflect in part the rising national concern with

helping students "learn how to learn." Almost every issue of the journal of the Association for Supervision and Curriculum Development (Educational Leadership) has articles on this topic extolling the merits of efforts to help students acquire "thinking skills." Another word of caution: a backlash is already developing in the American public that schools are so busy with numerous activities to teach "thinking skills" that too little subject matter is being taught! My own view is that most of the "thinking skill" programs lack solid underpinning in both the psychology of cognitive learning and in constructivist epistemology. They are too often an end in themselves, rather than a means to facilitate learning and thinking that places responsibility on the learner for constructing their meanings about subject matter. Concept mapping and Vee diagramming are two metacognitive tools that have had demonstrated success in this respect, as reported by a number of papers in Volume I of these Proceedings. From our perspective, we should like to see much more research done on the use of metacognitive tools to help teachers help students modify their misconceptions and form more valid and powerful conceptual frameworks.

In the mathematics groups in particular, but also in some of the science sessions, there was concern expressed regarding the importance of "procedural knowledge" as contrasted with "conceptual knowledge." Students often learn an algorithm or procedure for solving "textbook" problems but cannot transfer this skill to novel problem settings or across disciplines. They fail to understand the concepts that apply to the problems. The contrast between "procedural" and "conceptual" knowledge is, in my view, an artificial distinction. In our work with sports education, dance, physics, math and many other fields, we have never observed a procedure that could not be well represented with a concept/propositional hierarchy in a concept map. The limitation we see is that both strategies for problem solving and understanding basic disciplinary ideas derive from the

conceptual opaqueness of most school instruction. Mathematics, voice and dance instruction are particularly bad cases of conceptually opaque teaching. Metacognitive tools such as concept mapping can reduce some of the dilemma evidenced in concern for procedural versus conceptual learning to the need for more research and practice to help teachers help students see more clearly the conceptual/propositional frameworks that underlie meaningful learning and transferability of knowledge.

The role of the computer in science and mathematics education is emerging more prominently. Several sessions dealt with papers/discussion on the use of the computer as an educative tool, and numerous other sessions had one or more papers that reported on studies that involve computers in some way. The rapidly increasing power and stable cost of microcomputers, together with better and easier authoring systems, are changing significantly the application of computers in science and mathematics education. In many cases, the computer is not a substitute for class instruction but rather a tool for extending learning in class to novel problem solving or simulation constructions. The use of the computer to provide directly large amounts of raw data, or to permit access to large data banks, makes possible problem solving activities that border on original research, thus providing opportunities for creative problem generation and problem solving by students in ways that offer an experience paralleling creative work of scientists or mathematicians. The emerging use of video disc with computers and the emerging technologies for monitoring laboratory experiments should provide exciting new opportunities for science and mathematics instruction and also for the use of metacognitive tools. We expect to see much more activity reported in this area of future seminars of our group.

It is interesting to note in passing that while video tape was often recognized as a powerful tool in research on teaching/learning and for teacher education, not one paper reported on the use of TV as a primarily teaching vehicle.

The much heralded power of television as an instructional vehicle in the 1950's has not materialized. What will be the fate of computer aided instruction or interactive video instruction in 20-30 years?

On occasion, especially in sessions dealing with teaching and teacher education, it was observed that the school and classroom are complex social settings. We know much too little about how social factors facilitate or inhibit acquiring or modifying and correcting misconceptions, or indeed any other learning. There is a need for an enormous increase in studies dealing with the school/teacher/learner sociology as it relates to misconceptions research. We need to learn more about what sociologists, anthropologists and linguists are learning about how people communicate or fail to communicate positive ideas and feelings. It is my hope that our next international seminar on misconceptions will reflect more knowledge and awareness of these fields.

There remains much work to be done. And yet there are reasons for optimism. We are learning more about why students fail to learn and how to help teachers help students learn better. I believe the science of education is building a solid theory/research base, and positive results in improvement of educational practices are already emerging. The next decade should bear fruit in tangible improvement of science and mathematics teaching.

Reference

Helm, Hugh and Joseph Novak (eds.). Proceedings of the International Seminar Misconceptions in Science and Mathematics June 20-22, 1981. Ithaca, NY: Department of Education, Cornell University, 1983.

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Teaching Implications of Misconceptions in Probability and Statistics

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A few years ago in Italy the objectives for the Elementary School years were completely revised. For the first time, teaching the fundamental rules of logic, probability and statistics was officially stated as an objective. In stating this objective, the Italian Commission of the Ministry of Public Education explicitly noted that children's intuitive thinking about the rules of probability and statistics should be the basis of efforts to teach them the formal rules.

In this paper I will examine the soundness of this instructional policy and how it could best be implemented. First, I will consider the reliability of both adults' and children's intuitions about probability, and cite examples that demonstrate quite compellingly that intuitive thinking may lead to errors in problems involving logic-and probability. Second, I will describe a method I have used to train adults and children to use more formal rules and counteract the fallacies that result from intuitive thinking. Third, I will consider how such methods could be adapted for use in educational settings.

The seminal work by Kahneman and Tversky (Kahneman & Tversky, 1972; 1973; Tversky & Kahneman, 1971; 1973; 1974) demonstrated that adults' judgments are often inconsistent with normative rules of logic and probability. To explain these inconsistencies, they proposed that people often rely on judgmental heuristics, which are strategies for decision making based on intuitive or natural assessments. Although these heuristics provide valid judgments in many situations, in certain circumstances they lead to misconceptions.

My own research has focused on the representativeness heuristic, which is one of many heuristics proposed by Kahneman and Tversky. They (Tversky & Kahneman, 1983) note that an error in probabilistic reasoning called the conjunction fallacy can be caused by the representativeness heuristic. An example of the kind

of problem that may elicit the representativeness heuristic, causing the conjunction fallacy, is shown in Table 1.

Table 1

Example of an Adult Representativeness Problem

A health survey was conducted in a representative sample of adult males in British Columbia of all ages and occupations.

Mr. F. was included in the sample. He was selected by chance from the list of participants.

Which of the following statements is more probable?

- 1) Mr. F. has had one or more heart attacks.
- 2) Mr. F. has had one or more heart attacks and he is over 55 years old.

Adapted from Tversky & Kahneman, 1983.

Consistently subjects respond to the problem by identifying the second alternative as the most probable. This response is inconsistent with a fundamental rule of probability, which states that the probability of the conjunction of two events is less than or equal to the probability of either of the two events. In mathematical notation this rule is written as: $p(A \& B) \leq p(B)$. To explain this conjunction error, Tversky and Kahneman proposed that subjects judged the representativeness of the alternatives instead of their probabilities, and based their responses on these assessments of representativeness. The characteristic "having a heart attack" is commonly associated with the characteristic "adult males over 55 years." In many situations representativeness and probability covary, but when they are uncorrelated, judgments based on representativeness will lead to conclusions that are different from those reached with logical, extensional thinking.

For educational purposes, a central question is whether children are as susceptible as adults to heuristics. These heuristics may be learned through experience; if so, children have had less opportunity than adults to develop such heuristics. In the specific

case of the representativeness heuristic, we could argue that children have less world knowledge and they may be less schema-dependent than adults (a similar point has been made by Ross, 1981). It is important to know whether children are misled by such shortcuts in order to be able to decide upon the correctness of an educational policy that encourages teaching of probability and statistics based on intuitive thinking.

To investigate children's susceptibility to the representativeness heuristic, I conducted an Experiment with 9, 11 and 13 year-old children (Agnoli, 1987). Table 2 shows two questions I presented to Italian children. The first one asks, "In Summer at the beach are there more women or more tanned women?" This is clearly a representativeness question because the scenario elicits a representation in which tanned women are representative of women at the beach. The second one asks, "In Summer at the beach are there more women or more pale women?" This is clearly a non-representative question, because most women are not pale, at least at Italian beaches.

Table 2
Example of Representativeness Problem for Children

In Summer at the beach, are there:

- 1) more women or more tanned women?
(Representative question)
- 2) more women or more pale women?
(Non-representative question)

Each child was asked six representative and six non-representative questions. In Figure 1, the results of this experiment are presented. Obviously, children of all three age groups made a lot of errors for problems presented in the Representative format, many more than they made in the Non-Representative format. Clearly, children are highly susceptible to the representativeness heuristic.

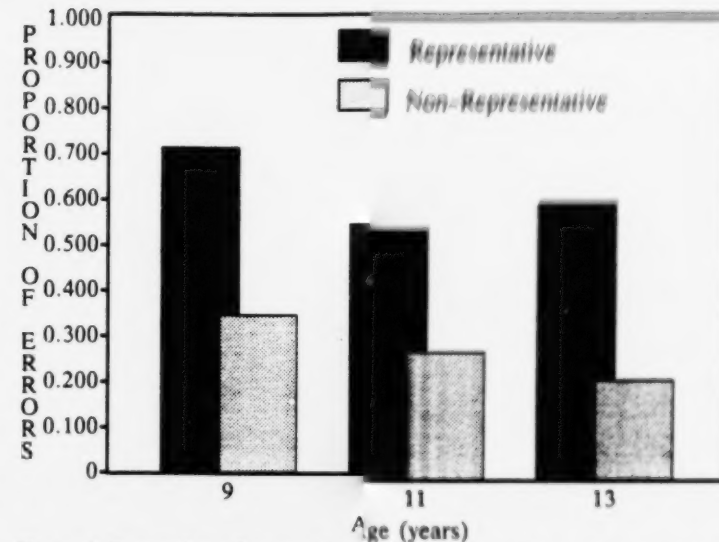


Figure 1. Proportion of errors for representative and non-representative problems in three age groups.

A conclusion that could be reached, looking only at the results reviewed so far, is that intuitive judgments of frequency and probability, both in children and adults, are a flawed starting point for teaching an understanding of logic and probability. An implication of this conclusion could be that we can only teach the "conservative" way, by starting from the formal rules and avoiding any links to misconceptions inherent in children's and adults' misconceptions. However, if ways are found to correct or counteract these misconceptions, then intuitions may be made a more sound basis for instruction.

Our recent experimental work may shed some light on this issue. In particular, we have shown that it is possible to reduce the effect of representativeness in adults' probability judgments as well as in simpler logical tasks performed by children. In both cases the effect was reduced through training that emphasizes the possible relationships among logical sets.

Agnoli and Krantz (1987) tested whether it was possible to train naive adult subjects to use logical rules, thereby making extensional comparisons, in problems like the one shown in Table

and, therefore, decrease the number of conjunction errors. We used a training session in which logical rules such as inclusion, disjunction, and overlapping were explained to subjects. Such relations were explained with simple examples through the use of Venn diagrams.

The relevance of the conjunction rule to the problem presented in Table 1 becomes much more apparent when the problem elements are presented in a Venn-diagram representation (see Figure 2). It is clear that the intersection (Men who have had one or more heart attacks and are more than 55 years old) is a subset of the other two sets, and therefore must be less frequent.

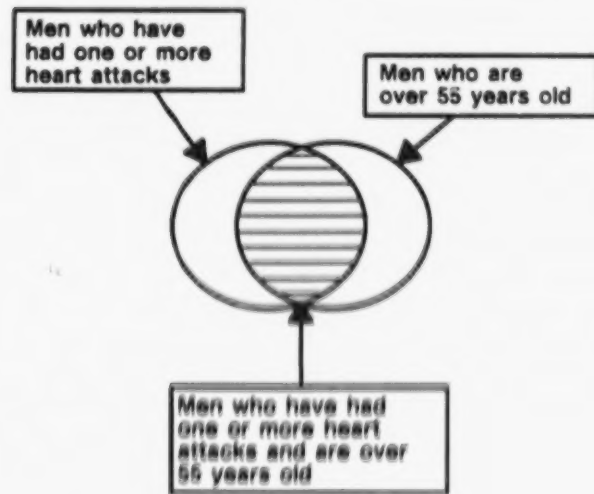


Figure 2. Venn-Diagram representation of the problem presented in Table 1.

Subjects were also trained to consider category size. By considering category size, subjects were trained to estimate the probability that an element is a member of a category. This training reduced dramatically the number of conjunction errors made by the naive subjects tested. We concluded from a series of experiments that people can gain an awareness of the misleading effects of the representativeness heuristic.

More recently, I conducted a series of experiments with subjects aged 11 to 13 to test whether children of this age could also learn to use normative logical rules and avoid those errors caused by the representativeness heuristic (Agnoli, 1987). The children were tested on problems in the Representative format like the one presented in Table 2. I developed a training module similar to the one we used with adults. In this training, children read about Venn-diagram representations of inclusion and disjunction, they were invited to draw Venn-diagram representations for logical categories, and the correct representations were presented. Finally, the correspondence between Venn-diagram representations and frequencies was explained. Figure 3 shows a Venn-diagram representation of the problem presented in Table 2.

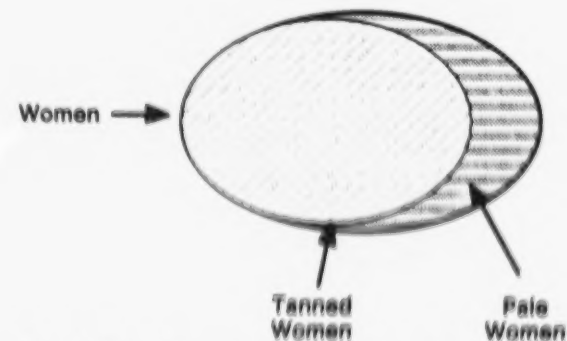


Figure 3. Venn-Diagram representation of the problem presented in Table 2, similar to Venn-diagrams used during training.

Children of both age groups were assigned to one of two groups. The procedure for the two groups was exactly the same, except that before the first set of problems, subjects in the training group completed the training module. Ten days later all children were tested again, with no further training. The results of this series of experiments (see Figure 4) showed that the logical training greatly reduced the frequency of errors for both ages. From an educational point of view, it is interesting to note the stability of this training effect over time. The training was effective not only immediately, but ten days later in the second session.

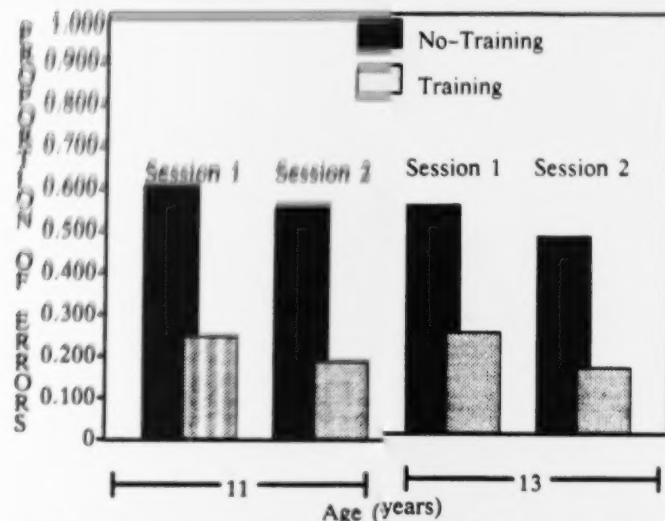


Figure 4. Proportion of errors for un-trained and trained subjects in Sessions 1 and 2.

In these experiments, subjects were asked to provide rationales for each choice. The rationales for representativeness responses almost always made reference to representativeness, whereas the rationales for logical responses almost always made reference to the elements of logical reasoning. This generalization held for both the control and the training groups.

The research I have reported (for both adults and children) points to areas in which misconceptions based on intuitive thinking lead to logical and probabilistic errors. I noted above that this research could suggest that intuitive judgments are a flawed starting point for teaching logic and probability, but that these intuitions could be made more sound by finding ways to correct the misconceptions inherent in intuitions. The training procedures I used to overcome the representativeness heuristic are a successful example of ways that such misconceptions can be counteracted. Such training procedures provide a formal procedure for solving problems that simultaneously may extend the subjects' intuitions about probability and statistics. Through use of such training procedures, people may learn the limits of their intuitions, recognizing when heuristics are and are not appropriately applied.

The research I have reported suggests that it is possible for subjects to learn about the effects of two different thinking systems, both intuitive and formal. I instructed adults and children, 11 and 13 years-old, about representativeness and compared it to the formalism of Venn-diagrams. The training session provided a tool for deciding which intuitions were valid and which intuitions, based on representativeness, led to violations of the conjunction rule or to frequency errors. The tool helped to substitute one behavior for another. The tool helped to serve as a perceptual external aid to ease construction of the correct mental representation when subjects drew the diagrams or as a memory tool when subjects confronted the problem without explicitly drawing Venn-diagrams.

In the area of medical decision making, Cole (1986) proposed a tool that overcomes another kind of probability misconception. He showed that a graphical representation could greatly simplify a difficult judgment problem that involved considering base rates. Base rate problems are common in the medical research area. For example, Cole considered the case of a 35 year-old woman who has tested positive for breast cancer, based on a test with characteristics such that people with the disease have a 95% chance of testing positive and people without the disease have a 90% chance of getting a negative result. The crucial issue in this problem is the necessity of taking into account base rates (that is, the prevalence of breast cancer in 35 year-old women). It has been repeatedly demonstrated, however, that adults do not take base rates into account in their judgments (Tversky and Kahneman, 1982). Cole (1986) showed that with the aid of a *probability map* the complex decision making becomes almost trivial. This map represents the frequencies of individuals who have a given disease and exhibit the symptoms of the disease. If a physician does not realize the implications of a low base rate for a disease, symptoms of the disease could be given too much weight. The probability map corrects this misconception.

It should be noted that intuitive thinking about probability and statistics is not always wrong. There have been instances in the literature showing that, at times, adults have effective "statistical" heuristics. For example, Nisbett, Krantz, Jepson and Kunda (1983) have argued that adults have a rudimentary understanding of the law of large numbers, and they point to the work by Piaget and

Inhelder (1975) to show that people in western culture learn at a very early age to recognize the probabilistic behavior of random generating devices.

A teacher concerned with instruction in logic, probability and statistics must recognize the often misleading role of "intuitive" heuristics at the same time as their strengths. Certainly intuitions can serve as the basis of efforts to learn more formal rules, as suggested by the Italian Commission of the Ministry of Public Education, but not without tools to help counteract those intuitions that lead to errors and misconceptions. The tools I have developed using Venn-diagrams are an effective way of counteracting the representativeness heuristic, and the probability map developed by Cole (1986) counteracts failures to consider base rates. There are many other heuristics that can lead to errors and misconceptions in probabilistic and statistical reasoning (Kahneman, Slovic, & Tversky, 1982). An effective educational program will require continued research on tools that counteract ineffective heuristics and expand the effectiveness of other heuristics.

References

- Agnoli, F. (1987). *Beyond representativeness: Tools for overcoming biases in children's reasoning*. Paper presented at the Society for Research in Child Development, Baltimore, MD.
- Agnoli, F., & Krantz, D. (1987). *Suppressing natural heuristics by formal instruction: The case of the conjunction fallacy*. Manuscript submitted for publication.
- Cole, W. G. (1986). Medical cognitive graphics. In *Proceedings of CHI'86 Human Factors in Computing Systems*, ACM: New York, 91-95.
- Kahneman, D., Slovic, P., & Tversky, A. (Eds.). (1982). *Judgment under uncertainty: Heuristics and biases*. Cambridge: Cambridge University Press.
- Kahneman, D., & Tversky, A. (1972). Subjective probability: A judgment of representativeness. *Cognitive Psychology* 3, 430-454.
- Kahneman, D., & Tversky, A. (1973). On the psychology of prediction. *Psychological Review*, 80, 237-251.
- Nisbett, R. E., Krantz, D. H., Jepson, C., & Kunda, Z. (1983). The use of statistical heuristics in everyday inductive reasoning. *Psychological Review*, 90, 339-363.
- Piaget, J., & Inhelder, B. (1975). *The origin of the idea of chance in children*. New York: Norton.
- Ross, L. (1981). The "intuitive scientist" formulation and its developmental implications. In J. H. Flavell, & L. Ross, (Eds.), *Social cognitive development: Frontiers and possible futures*, Cambridge: Cambridge University Press.
- Tversky, A., & Kahneman, D. (1971). The belief in the "law of numbers." *Psychological Bulletin*, 76, 105-110.
- Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, 5, 207-232.
- Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185, 1124-1131.
- Tversky, A., & Kahneman, D. (1982). Evidential impact of base rates. In D. Kahneman, P. Slovic, & A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases*. Cambridge: Cambridge University Press.
- Tversky, A., & Kahneman, D. (1983). Extensional versus intuitive reasoning: The conjunction fallacy in probability judgment. *Psychological Review*, 90, 293-315.

Using Vee Diagrams To Clarify Third-Grade Students'
Misconceptions During A Science Experiment

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This paper reports the results of an initial attempt to investigate the effectiveness of a Vee diagram in helping third grade elementary school students learn science concepts meaningfully. A Vee diagram is a structured, visual means of relating the methodological aspects of an activity (such as a science experiment) to the underlying conceptual aspects. It focuses on the salient role of concepts in learning and retention.

Theoretical Framework

Gowin's (1981) theory of educating, Ausubel's (1963, 1968) cognitive theory of meaningful reception learning, and a constructivist epistemology provide the philosophical and theoretical background upon which this investigation was designed and through which the results were interpreted. Gowin's theory of educating focuses on the educative event and its related concepts and facts. This theory is helpful in classifying the relevant aspects of the educative event and its related concepts and facts. In an educative event, teachers and learners share meanings and feelings so as to bring about a change in the human experience. This theory stresses the centrality of the learner's experience in educating. Ausubel's learning theory places central emphasis on the influence of students' prior knowledge on subsequent meaningful learning.

Epistemology is a philosophical term that deals with the nature of knowledge and how knowledge is produced. Philosophers such as Gowin (1981), Toulmin (1972), and Brown (1979) feel that knowledge is constructed from experience using concepts as stepping stones. Concepts are signs/

symbols that point to regularities in events or objects (Gowin, 1981). Concepts are usually identified by words, but they may be numerical or symbolic (such as musical notations or mathematical symbols). For example, those objects that have markings peculiar to a specific nation (i.e., stars and stripes), and which are hoisted and suspended from a pole, show the regularity that we designate with the symbol U.S. flag. Events are defined as anything that happens naturally (e.g., thundershower, tornado, volcanic eruption) or can be made to happen (e.g., soccer match, school play, art exhibit, orchestra recital, faculty meeting, AERA Conference). Objects are defined as anything that exists and can be observed. For example, birds, snow, mountains, and volcanoes are naturally occurring objects; flags, books, bridges, and robots are objects that humans construct.

The Vee heuristic was developed by Gowin to enable students to understand the structure of knowledge (e.g., isolated facts, relational networks, hierarchies, combinations) and processes of knowledge construction (Gowin, 1981; Novak & Gowin, 1984). The fundamental assumption is that knowledge is not absolute, but rather it is dependent upon the concepts, theories, and methodologies by which we view the world. This assumption is supported by current views of epistemology (Brown, 1979; Kuhn, 1962; Toulmin, 1972). The philosophical basis of the Vee diagram makes concepts, and propositions composed of concepts, the central elements in the structure of knowledge and the construction of meaning. The learning theory that exemplifies concept and propositional learning as the basis on which individuals construct their own meanings is espoused by Ausubel (1963, 1968; Ausubel, Novak & Hanesian, 1978). The primary concept in Ausubel's theory is meaningful learning. To learn meaningfully, individuals must choose to relate new knowledge to relevant concepts and propositions they already know. The

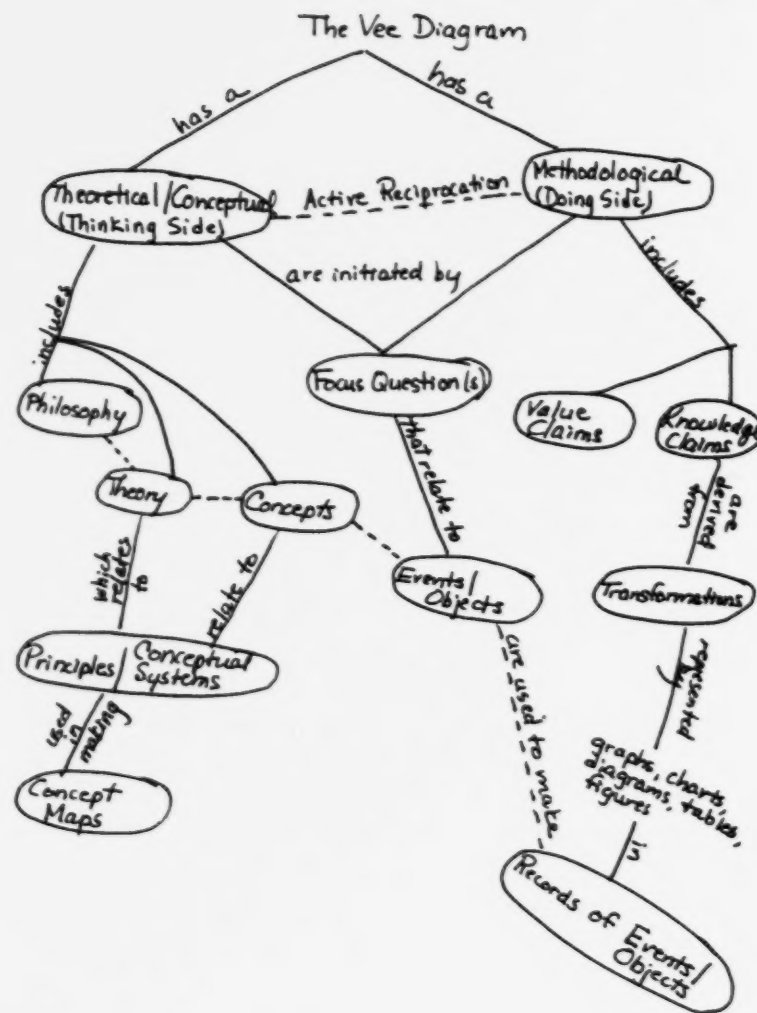
Vee diagram is a tool for acquiring information about knowledge and how knowledge is constructed and used.

Vee diagramming has proven to be successful as an instructional heuristic with college students (Chen, 1980; Leahy, 1986; Taylor, 1985). Vee diagramming has been investigated in ninth and eleventh grade science classes (Gurley, 1982), and with junior high school students (Novak, Gowin, & Johansen, 1983).

A concept map depicting the Vee is shown in Figure 1. A concept map is a visual representation of a person's thought processes. It is portrayed visually in a hierarchical fashion and represents concepts and their interrelationships. As can be seen and read from the concept map, the Vee diagram separates conceptual (thinking) from methodological (doing) elements of inquiry. Both sides actively interact with each other through the use of the focus question(s) that directly relates to events and/or objects. This interaction is depicted by broken lines indicating cross links. Cross linkages show meaningful relationships between segments of the concept hierarchy.

The conceptual side includes philosophy, theory, principles/conceptual systems (which include developing a concept map), and concepts all of which are related to each other and to the events and/or objects which, in turn, are used to make records of the events and/or objects are transformed into graphs, charts, figures, transcriptions of audio or video tapes, and so forth and become the basis to make knowledge and value claims. While there is no set way in which to read a Vee diagram (either from left to right or right to left, top to bottom, bottom to top, or anywhere in between), it is advisable to begin with the educative events as the point of the Vee followed by the focus question(s). The reason for such a progression is that the educative event is paramount in determining the focus question(s) for the

Figure 1. Concept Map of a Vee Diagram.



inquiry and the subsequent interplay among the conceptual and methodological elements.

The structure of knowledge on the Vee refers to the results or products of the inquiry. Structure, in Gowin's Vee, means the elements and their relation to each other. Gowin (1981, pp. 87-88) defines the "structure of knowledge" by capsulizing his remarks of an earlier paper (Gowin, 1970):

The structure of knowledge may be characterized (in any field or exemplar of that field) by its telling questions, key concepts and conceptual systems; by its reliable and relevant methods and techniques of work; by its central products; by its within-field and outside-the-field values; by its agents and audiences (the so-called "community of scholars"); and by the phenomena of interest the field deals with and the occasions which give rise to the quest for knowledge.

The purpose of this study was to determine if Vee diagrams could be taught, understood, and used meaningfully by third grade students in learning concepts in a science experiment.

Methods and Materials

This study was conducted over a three month period in an elementary school in a large metropolitan school district in Tennessee. Twenty-eight third-graders and their teacher participated in this study. Twenty-six children in the third grade class were tested the year before with the Stanford Achievement Test, Form F, Level 4. These children had reading stanine scores ranging from 4 through 9. Of the remaining two students, one had been tested with the Iowa Test of Basic Skills, Form 7 (1985) and the other had no test records. Overall, this class was judged by the classroom teacher to be slightly above average.

First, the teacher was instructed on the purpose and use of concept maps. Knowledge of concept maps is a prerequisite to the introduction of Vee diagrams. Students developed concept maps with the unit of study prior to introducing the Vee diagram. Next, the teacher was instructed on the terminology of the Vee and the relationship of each element

on the Vee to aspects of their reading assignments. She then instructed her class on the purpose, terminology, and use of Vee diagrams.

The teacher introduced examples of concept maps and Vee diagrams associated with the assigned lessons. Next, she introduced a skeletal Vee diagram that contained headings: focus question, event/object, concepts to be investigated, records, transformations, knowledge claims, value claims, theory, and principles. The Vee diagram was associated with the assigned readings in their science textbook. The researchers developed the science experiments that were used in this investigation. These materials were developed in accordance with the topic that was currently being studied by the third graders. The teacher was instructed on the stratified random sampling procedure. She was then asked to make a stratified random assignment of her students by placing them into six groups, based on either their reading stanine scores or (as in the case of the one student without a test score) teacher placement. The teacher was asked to keep a daily journal recording her reflections and intervention with the students as a whole and individually, she also kept student taped interviews. She was asked to conduct this experiment using her teaching style and time constraints as part of her normal preparation and classroom procedure. In this study, students worked in groups in preparing their individual Vee diagram.

For this study, a science experiment investigating "sprouting plants" under four conditions was conducted. All four conditions contained lima beans that had been soaked overnight in water and then were placed in a jar suspended between paper toweling and the inner glass. The four conditions were: (1) an inch of water at the bottom of the jar with wet paper toweling with the top opened; (2) an inch of water at the bottom of the jar with wet paper toweling with a plastic covering so that air could not get in; (3) an

inch of water at the bottom of the jar with wet paper toweling with the top opened placed in a dark compartment without light; and (4) no water in the jar with dry paper toweling with the top opened. Students kept records of the events over a six day period.

The records and performance measures made of the educative events during this study included copies of student Vee diagrams, anecdotal notes made by the teacher and researchers, and audiotapes and transcriptions of students' interviews. To study these teacher/student relationships, McDermott's (1977) anthropological definition of ethnography was used. In this context, ethnography is defined as "any rigorous attempt to account for people's behavior in terms of their relations with those around them in differing situations." (p. 200). Within this definition we included the gathering of thoughts that were generated as a result of these social interactions. How social interactions in classroom settings affect conceptual learning is a major thrust of this report.

The records were summarized and transformed through an analysis of the teaching, learning, curriculum, and governance components proposed by Gowin (1981). Scoring procedures followed the protocol suggested by Novak and Gowin (1984, pp. 70-72). Vee diagrams were scored on a quality point scale (0-4) with a maximum score being 18 using the following criteria (point values in parentheses for each of the categories): focus question (0-3), objects/events (0-3), theory, principles, and concepts (0-4), records/transformations (0-4), and knowledge claims (0-4).

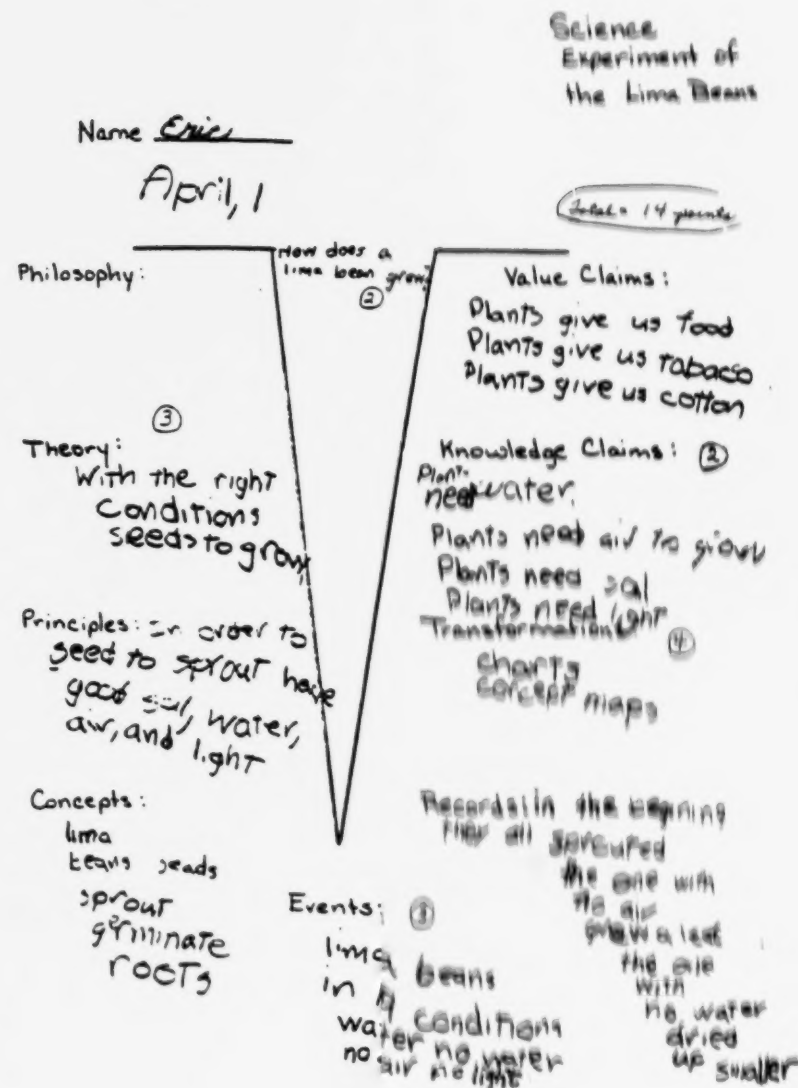
An example of a Vee diagram constructed by a third grade student is shown in Figure 2. Circled number represent points assigned to each category with a maximum score of 18.

Results and Conclusions

Vee diagrams constructed by the students were collected for the designated science experiment and scored by the

Figure 2.

Example of a scored Vee diagram prepared by a third grade student.



10 researchers (interrater reliability .96) using the scoring procedures described above. All scores were in a range of 11 to 16 (maximum score 16). Descriptive data indicated that all students were successful in using the Vee. The frequency distribution and percentage of raw scores are presented in Table 1.

Table 1. Frequency distribution and percentage of total individual raw scores.

Raw Score	f (n=28)	%
11	2	61
13	11	72
14	9	77
15	5	83
16	1	88

There was no differentiated effect according to ability level. Total scores for stanines 4, 5, and 6 were 164; stanines 7, 8, and 9 totaled 207. Mean scores were 13.7 and 13.8 respectively (see Table 2).

Table 2. Total individual raw score, frequency distribution, and percentages according to average and high reading comprehension stanine scores

Stanine Score	Raw Score	f (n=27)	%
Average			
4	13	3	72
	14	2	77
5	13	2	72
	15	2	83
	16	1	88
	11	1	61
6	14	1	77

High

7	13	4	72
	14	1	77
	15	1	83
8	14	3	77
	15	1	83
9	13	2	72
	14	2	77
	15	1	83

Anecdotal records indicated that learning strategies that require comprehending subject matter demands concentrated study, but suggest most students recognize and value understanding over rote learning. All students were able to complete the designated component parts of the Vee with success.

Student interviews indicated that Vee diagrams helped them to understand what was taking place in the experiment by keeping records of the events. Students indicated that they found making charts of the records and concept maps of the results of the experimental helpful in understanding the idea of "sprouting seeds."

When Vees were individually analyzed by group, they revealed commonality associated with a particular group. Students in the same group tended to conform when making their Vees. This seems to suggest that social and communicative interaction during the educative event contributed to different constructions of knowledge achieved through negotiation. This depended upon the respective group interaction (see Table 3).

Table 3. Total individual raw scores, percentages, and stanine scores by group. Mean score of each group in parentheses.

Subjects (n=28)	Stanine Score	Raw Score	%
Group 1 (12.2)			
1	4	11	61
2	7	13	72
3	7	13	72
4	8	13	72
5	8	11	61
Group 2 (14.0)			
6	8	14	77
7	5	14	77
8	9	14	77
9	9	14	77
10	5	14	77
Group 3 (15.2)			
11	9	15	83
12	5	15	83
13	5	15	83
14	5	16	88
15	8	15	83
Group 4 (13.6)			
16	9	14	77
17	7	14	77
18	7	13	72
19	8	14	77
20	4	13	72
Group 5 (13.0)			
21	9	13	72
22	4	13	72
23	4	13	72
24	5	13	72
Group 6 (13.7)			
25	7	15	83
26	7	13	72
27	8	14	77
28	4	13	72

* NO TEST RECORDS

One way ANOVAs to determine differential effects across groups revealed that the mean score of Group 3 was significantly different from the other five groups, $E(5, 21) = 10.8, p < .001$. A post hoc analysis using the Newman-Keuls test showed that Groups 2, 4, and 6 were significantly different from Group 1, $p < .05$. It is interesting to note the make-up of students and their stanine scores for Group 3. The student with a stanine of 5 had a higher raw score than the two with 8 and 9 stanines. When analyzing stanine scores and raw scores within groups, students with higher stanines did not necessarily have higher raw scores than those students with lower stanines. Overall, the Vee diagrams tended to reflect a group consensus.

The teacher indicated that students became more interested in the experiment and were able to discuss the knowledge claims in relation to their focus question and events. She was pleasantly surprised at their being able to generalize their findings into value claims that varied depending upon the group. She found that the Vee diagram provided her with an evaluation instrument to determine how well students had understood and were able to relate their findings of the results. This, in turn, enabled her to provide feedback as to their understanding of concepts (e.g., sprout, germinate) through a visual inspection of the array of relationships among the concepts that pertained to the various knowledge structures of the experiment.

The evaluative effects of the Vee is illustrated by the following circumstance. An inspection of the Vee's showed that 57% of the students generated knowledge claims that related to their principles and not to their records (i.e., plants need air to grow, but they grew even when they didn't have air). On the surface there seemed to be a discrepancy between these two items. However, an interview with the teacher showed that the plastic covering on the jar was not air tight. In fact, it fitted loosely. She reported that this portion of the experiment was repeated and that these

- 12 students then understood that air was needed for the seeds to sprout thereby clarifying their misconceptions and accounting for their notation under principles.

Both the students and the teacher felt that Vee diagrams aided conceptual understanding of the processes and products of the experiment. They felt that more was accomplished by going beyond the traditional "writing down the facts" (records) by charting the data, making knowledge claims, developing a theory and stating a principle. They found this lesson to be interesting, challenging and exciting.

Conclusions

In this preliminary study, Vee diagrams seem to be a viable tool in learning about the structure of knowledge and the processes of knowledge production (metaknowledge). They enabled third-grade learners to delve into a piece of knowledge and come away with a deeper understanding of how knowledge is constructed by showing how the concepts, events/objects, and records of the events/objects are intermingled when attempting to create new knowledge.

These third graders were able to learn concepts associated with the science experiment. They were able to relate and complete the designated components of the Vee with success and understanding. These science concepts were learned in a meaningful rather than a rote manner. Students were able to discuss these concepts in meaningful contexts with each other and with the teacher. They were able to make connections, structure their knowledge, and create meaning.

Students were free to express their emotions and thoughts, make predictions, and raise questions. The teacher also became an active learner and observer as well as a partner in the experience. She learned (a) about two methods (concept maps and Vee diagrams) that help students learn new information in a meaningful manner; (b) that she was able to incorporate these methods into her array of teaching practices; and (c) during the process, how to plan and

collect data for the study of student learning. In essence, she became the researcher for her class.

There seemed to be no difference in constructing Vee diagrams between the average and high reading ability students. However, this task required more record keeping and problem solving of the events that were taking place than it did reading and therefore was not necessarily based on how well a student could read. Even though some students were randomly interviewed prior to the experiment by the teacher concerning their knowledge about sprouting seeds, it may be that prior knowledge and/or background experiences from students not interviewed accounted for differing scores within and across groups. Overall, the Vee diagrams tended to represent a group consensus suggesting social interactions among students resulting in negotiation in their construction.

Vees act as an evaluation instrument for both the teacher and the student in determining how well ideas are represented among the component parts of the Vee diagram. As shown in this study, the sharing of meaning of the educational experiences between peers and the teacher helped in resolving conflict and uncertainty in resolving the discrepancy between those students who formulated principles based on inaccurate knowledge claims. The teacher was able to read the Vee and rectify misconceptions that caused the students difficulty in organizing and relating ideas on the Vee. Together, the teacher and the student, were able to resolve uncertainties or misunderstandings and make the educative event a meaningful learning experience. Responsibility for learning science concepts took on a new dimension through the use of Vee diagrams.

The use of Vee diagrams needs to be tested for their generalizability and independent use with this population. Studies with this population need to be conducted to determine how well students are able to generate Vee diagrams individually and with peers. Specifically, it needs to be

determined: (1) how well students are able to recognize what events or objects they are observing; (2) to what extent do they make use of their prior knowledge in relation to these events and objects; (3) how decisions are made to decide what records need to be made; and (4) the processes that are used in formulating focus questions that direct the inquiry based on the events/objects to be studied.

The focus question(s) elicits reflective thought and inquiry on the part of the students. Students are made to think about what they already know about the topic. It gives them direction to find out what they don't know and what they have to do to understand (in this particular experiment) the conditions under which lima beans sprout. It is through this focus question(s) that events/objects, records, transformations, and knowledge claims develop and new knowledge is learned.

Vee diagramming is a way to help students and teachers penetrate the structure of meaning of knowledge they seek to understand. Being able to get the right answer is sufficient in many school evaluations upon which grades are based, and too often only rote recall is needed to answer questions. Teachers when versed in Vee diagramming seem to be receptive to this learning strategy in order to achieve meaningfully rather than rote verbatim learning, and see this strategy as an independent learning aid to be used by the learner. A link between learning theory and teaching can be made through the use of Vee diagrams. Waterman (1982) suggests that a conceptual change approach to teaching should include explicit ways for students to become aware of their own beliefs and to come to understand the nature and construction of knowledge. This investigation lends credence to such an observation.

References

- Ault, C. R., Novak, J. D., & Gowin, D. B. (1984). Constructing Vee maps for clinical interviews on molecule concepts. Science Education, 68, 441-463.
- Ault, C. R., Novak, J. D., & Gowin, D. B. (1986). Constructing Vee maps for clinical interviews on energy concept. Manuscript submitted for publication.
- Ausubel, D. P. (1963). The psychology of meaningful verbal learning. New York: Grune and Stratton.
- Ausubel, D. P. (1968). Educational psychology: A cognitive view. New York: Holt, Rinehart and Winston.
- Ausubel, D. P., Novak, J. D., & Hanesian, H. (1978). Educational psychology: A cognitive view, 2nd ed., New York: Holt, Rinehart and Winston.
- Brown, H. I. (1979). Perception, theory and commitment: The new philosophy of science. Chicago, IL: University of Chicago Press.
- Chen, H. H. (1980). Relevance of Gowin's structure of knowledge an Ausubel's learning theory to methods for improving physics laboratory instructing. Unpublished master's thesis, Cornell University, Ithaca, New York.
- Gowin, D. B. (1970). The structure of knowledge. Educational Theory, 20, 319-328.
- Gowin, D. B. (1981). Educating. Ithaca, New York: Cornell University Press.
- Gowin, D. B. (1986, March). Reading and writing: Concept maps and Vee diagrams. Paper presented at the Center of Excellence, Basic Skills for the Disadvantaged, Second Annual Visiting Scholars Conference, Nashville, Tennessee.
- Gowin, D. B. (1986, June). Epistemic elements in evaluation research: Proposals for improving research and policy recommendations for services to handicapped youth. A paper prepared for Professor Robert Stake, University of Illinois Transition Institute Project.
- Gowin, D. B. (Speaker) (1986). Reading and writing: Concept maps and Vee diagrams. (Cassette Recording). Nashville, Tennessee: Center of Excellence, Basic Skills for the Disadvantaged, Visiting Scholars Conference.
- Gurley, L. I. (1982). Use of Gowin's Vee and concept mapping strategies to teach students responsibility for learning in high school biological sciences. Unpublished doctoral dissertation, Cornell University, Ithaca, New York.
- Kuhn, T. S. (1962). The structure of scientific revolutions. In International Encyclopedia of Unified Sciences, 2nd ed., Chicago: University of Chicago Press.
- Leahy, R. M. (1986). Using a theory of educating to enhance students' autonomy and authenticity. Unpublished doctoral dissertation, Cornell University, Ithaca, New York.
- McDermott, R. P. (1977). Social relations as contexts for learning in school. Harvard Educational Review, 47, 198-213.

- Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. New York: Cambridge University Press.
- Novak, J. D., & Gowin, D. B., & Johansen, G. T. (1983). The use of concept mapping and knowledge Vee mapping with junior high school science students. Science Education, 67, 625-645.
- Taylor, M. R. (1985). Changing the meaning of experience: Empowering learners through the use of concept maps, Vee diagrams, and principles of education in a biology lab course. Unpublished doctoral dissertation, Cornell University, Ithaca, New York.
- Toulmin, S. (1972). Human understanding, Vol. 1, The collective use and evolution of concepts. Princeton, NJ: Princeton University Press.
- Waterman, M. A. (1982). College biology students' beliefs about scientific knowledge: Foundations for study of epistemological commitments in conceptual change. Unpublished doctoral dissertation, Cornell University, Ithaca, New York.

JUSTIFICATIONS OF ANSWERS TO MULTIPLE CHOICE ITEMS AS A
MEANS FOR IDENTIFYING MISCONCEPTIONS

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INTRODUCTION

In recent years there has been a growing interest in misconceptions which are prevalent among students. A wide acknowledgement exists that misconceptions: (a) are quite widespread among students in many subject areas of science; (b) are very persistent and difficult to change or replace; (c) affect subsequent learning (Smith and Lott, 1983; Nussbaum and Novick, 1982).

Various means and methods are described in the literature for identifying misconceptions. By far the most widely used is the clinical interview (Gilbert, Osborne and Fensham, 1982, Nussbaum, 1979). This method has the advantage of providing excellent in-depth information about the student's conceptions. However, it has some serious drawbacks: (a) it is time and labor intensive and thus difficult to apply to large numbers of students; (b) the potential for generalizing the findings to large groups of students is rather limited.

Attempts have been made to use paper and pencil tests in order to collect data from more students than can be reached through clinical interviews. In some cases these instruments were based on findings from a limited number of interviews. Such studies were reported by Bell (1985), Wandersee (1983), Arnold and Simpson (1982), Barker (1985), Brumby (1979), Simpson and Arnold (1980).

Two types of question formats were used in these studies, open-ended short essay and multiple choice. Combinations of formats were used by Brumby (1979). In her study, the same item was presented to the students twice: first as an open-ended and

then as a multiple choice. Differences between the responses to the two formats were not reported. Wandersee (1983) added a requirement for additional explanation on some of the items on the Photosynthesis Concept Test (PCT). A partial analysis of the written explanations is reported and a selection of explanations is cited. Staver (1986) also used combination items: completion + multiple choice + justification and completion + essay. Achievement on the reasoning task given to the students was found to be affected by the item format only on unfamiliar or complicated tasks. Treagust and Haslam (1986) and Peterson, Treagust and Garnett (1986) followed Tobin and Capie (1981) and designed two-tier items in the explicit purpose of identifying misconceptions. The first tier consists of a multiple choice item and the second contains four possible justifications for choices of the first tier. The student has a double task: first he has to choose the correct answer among the 2-4 choices of the first tier and then he has to choose a justification to support his choice. From the examples brought by Treagust and Haslam (1986) it can be seen that formulating justifications which might support all the options of the first tier is not always easy. In some cases the choice on the first tier channels the student to a certain response on the second tier and not to others. The end result of such a situation is that no additional insight into the thinking of the student has been achieved.

We would like to report a novel approach to the identification of misconceptions among large groups of students. For some years now, students who take the biology matriculation (Bagrut) exam at the end of year 12 are required to give justifications to the choices made on selected multiple choice items. The items selected for this task are of high cognitive level (comprehension and above).

The justifications given by the students were in the form of short answers usually 2-3 sentences long. The achievement results for the year 1985 (N=2405) indicated that the mean score on the justifications task was about 17 percentage points (more

16 than full standard deviation) lower than the mean multiple choice score.

In this study the justifications were analyzed for the purpose of uncovering misconceptions of the students. The following questions were studied:

1. What is the effectiveness of justifications for multiple choice items as a means for identification of misconceptions?
2. What are the prevalent misconceptions related to the different subject areas?

The subject areas dealt with in the items analyzed in this study were also touched upon in investigations by other groups as well as by us:

Osmosis: Friedler, Amir and Tamir (1986), Arnold and Simpson (1982), Murray (1983).

Genetics: Stewart (1982), Hackling and Treagust (1984), Longden (1982), Tolman (1982).

Aspects of Plant Nutrition: Smith and Anderson (1984), Simpson and Arnold (1980), Wandersee (1983), Bell (1985), Stavi et al (1987).

As we describe the findings of our study we shall refer to some of the studies mentioned above.

METHOD

Sample

The sample comprised of 354 students from 18 schools, out of 2405 students who took the matriculation exam* in 1985. Schools were selected according to their students' achievement in the multiple choice section of the exam in past years. The stratified sample thus consisted of students from 4 low achieving

* This group took the lower level (2-3 points) exam.

schools (mean score 65, n=91), 6 average achieving schools (mean score 66-75, n=108) and 5 above average achieving schools (mean score 76, n=97). For 3 schools (n=58) achievement data for 1985 was not available.

Procedure

Four items were selected for the justifications tasks. For each item we constructed a key for the analysis of justifications. The construction of the key included the following steps:

1. Free reading of justifications to obtain a general impression.
2. Defining aspects for the justifications for each item.
3. Establishing levels in each aspect. These levels ranged from "not mentioned" to "correct." The intermediate levels were assigned to partial answers or specific misconceptions.

RESULTS AND DISCUSSION

Results for each item are described and discussed separately. Wherever an example of a student's justification is cited an attempt has been made to preserve the student's actual wording while translating his justification into English. The Results for each item are given in tables which comprise two parts: Part A gives the distribution of responses to the multiple choice item and Part B gives the results of the analysis of the justifications, for all the respondents and for selected groups of students.

ITEM 1

Item 1 (Table 1) deals with Mendelian genetics -transmission of sex linked gene from parent to offspring.

Genetics is a subject which is taught in several grade levels throughout high school. Longden (1982) identifies three "areas of concern" related to the study of genetics in high

TABLE 1: Descriptive results for Item 1 (N=308)

PART A: Distribution of responses (in percentages) to Item 1.	
A GENE ON CHROMOSOME X IS NOT TRANSMITTED FROM:	
	Response (percent)
*1. the male to his male sons	78
2. the male to his male grandchildren	12
3. the female to her daughters	6
4. the female to her grandchildren	4

PART B: Distribution (in percentages) of aspects of the justifications.

Aspects	all respondents (N=290)	distribution (percent) students who chose option 2 or 4 (N=46)	
		option 2	option 4
A: Types of gametes transmitted from father to offspring			
not mentioned	40	32	66
wrong	11	8	28
correct (Y to son or X to daughter or: Y to son and X to daughter)	49	60	6
B: Types of gametes transmitted from mother to offspring			
not mentioned	59	53	85
wrong (mother transmits to daughters only)	5	3	4
correct (X to daughter or: X to both sons and daughters)	36	44	11

*correct choice

TABLE 2: Descriptive results for item 2 (N=312)

PART A: Distribution of responses (in percentages) to Item 2.	
A WHEAT SEED WAS PLANTED. FROM THE SEED GROW A PLANT WHICH DEVELOPED A CROP OF 100 SEEDS. WHAT ARE THE SOURCES OF THIS CROP.	
	response (percent)
1. Minerals from the soil	1
2. Water and minerals from soil and oxygen from the air	13
*3. CO ₂ from the air and water and minerals from the soil	44
**4. Water, minerals and organic substances from the soil	22

PART B: Distribution (in percentages) of aspects of the justifications.

Aspects	all respondents (N=312)	distribution (percent) students who chose option 3 (N=200)		all students who chose option 4** (N=69)
		option 3	option 4**	
A. Photosynthesis as a process				
utilizing CO ₂	46	24	85	
not mentioned	5	2	12	
wrong: plant respire CO ₂				
partial: CO ₂ "produce" 2 photosynthesis	2	4	0	
correct: CO ₂ used in photosynthesis	47	70	3	
B. Absorption of materials from soil				
not mentioned	20	19	20	
wrong: organic compounds	21	6	75	
partial: water or minerals	5	6	2	
correct: water and minerals	53	70	3	
C. Source of the crop				
not mentioned	47	52	25	
wrong: organic compounds from soil	27	8	75	
partial: photosynthesis only	12	18	0	
correct: photosynthesis and water and minerals	14	22	0	

* correct choice

**misconception distractor

school: (a) genes, alleles, chromatids and chromosomes; (b) replication of DNA and meiosis; (c) symbolic representation and mathematical bias. Replication of DNA and meiosis seems to be a major obstacle in understanding inheritance as found also by Stewart (1982), Tolman (1982) and Hackling and Treagust (1984). Tolman (1982) states that "students can explain with relative ease the parental source of the X and the Y chromosomes." Our results, however, point to the existence of difficulties in this area which might stem from misunderstanding of the segregation of chromosomes during meiosis.

Results of the choices which were made by the students on the multiple choice item show that 78% of the students chose the best answer (option 1). Sixteen percent chose options 2 and 4. These students probably think that genes cannot pass from grandparents to grandchildren. Examples:

- * "A gene on X chromosome cannot pass to his grandchildren since the male can contribute genes on a chromosome to his sons and daughters but not to his grandchildren, because the genes on the chromosome of the grandchild will be determined by his own parents and not by his grandfather."

Six percent of the students chose option 3. These students probably think that the X chromosome is not transmitted from mother to daughter or confuse the X and the Y chromosomes:

- * "Only the male has an X chromosome, that is why the gene cannot pass from the female to her daughters. The female has Y chromosomes."

The analysis of justifications revealed two aspects:

- A: Which types of gametes are passed on from the male to his offspring.
- B: Which types of gametes are passed on from the female to her offspring.

A full correct justification to the best answer had to refer only to the fact that all male offsprings receive from their fathers a gamete which includes a Y chromosome and not an X chromosome (Aspect A). As can be seen from Table 1, 60% of those who made the correct choice also justified their choice correctly:

- * "Because if an X chromosome is transmitted from the father, the fetus will be a female and not male. If the father contributes a Y chromosome it will be a male. That is why it is not transmitted."
- * "Because the female is the one who transfers the X chromosome and therefore it is impossible for the man to transfer this chromosome."

Thirty-two percent did not mention the type of gametes at all:

- * "A gene on the X chromosome is responsible for female heredity."

Forty-four percent of the students who chose the best answer also included in their justification a correct statement regarding the female sex chromosomes (Aspect B).

Even more interesting are the justifications of those students who chose options 2 or 4. Ninety-four percent of them either did not refer at all to the types of gametes which are transmitted or refer to in a wrong way. Since aspect A was essential for a correct justification one can conclude that the problem of those students was not understanding the continuous transmission of genes through generations.

It can be concluded that although a large proportion of the students identified the best answer, their understanding is deficient. They fail to realize what is the mechanism which is responsible for the pattern of inheritance described in the item (X linked traits cannot be transmitted from father to son). This

lack of understanding could only be revealed through the analysis of the justifications.

ITEM 2

Item 2 (Table 2) dealt with plant growth and development. Specifically it required from the student to show understanding of the role of photosynthesis and soil in production of organic matter.

The analysis of the justifications for item 2 revealed three aspects:

- A. Photosynthesis as a process utilizing CO_2 .
- B. Materials absorbed from the soil.
- C. Sources of added organic matter in the wheat plant.

In each justification, usually more than one category was mentioned. Table 2 gives the response distribution to the four options and the distribution among the aspects. Aspects A and C were considered to be essential for a correct justification.

From the results shown in Table 2 (Part A) it can be seen that the choices students make on multiple choice items can, by themselves, reveal misconceptions. Inspection of options 2, 3 and 4 show that all include "water and minerals" but differ on whether an additional substance should be CO_2 , oxygen or organic compounds. The results show that 22% of the students believe that organic compounds in the soil are the source of organic matter. This misconception was found and discussed in many studies from all around the world and across age levels (Simpson and Arnold, 1980; Wandersee, 1983; Bell, 1985; Smith and Anderson, 1984). Another 13% of the students view oxygen as the main contributor of additional matter.

Analysis of the justifications (Table 3, Part B) however, provides us with a better insight into the way students think about plant growth. A quarter of the students who chose the correct answer (option 3), could not adequately relate it to

photosynthesis (Aspect A) as evidenced by the following examples:

- * "Plants take in CO_2 and release O_2 . Plants need water and food to grow. Water they get from the soil and the minerals are their food."
- * "The plant needs sources of food and drink which are the minerals and the water, which are absorbed from the soil. The plant also needs CO_2 for breathing."

Another 6% mentioned the process of photosynthesis but in a partial or wrong way:

- * " CO_2 is used by the plant for breathing and for performing better photosynthesis."
- * " CO_2 is absorbed by the plants as they respire (breath)^{*} and is used to produce energy. With the help of this energy the plant makes additional materials which are needed for the building of more cells. The water and the minerals which are absorbed from the soil are the plant's food. The water is broken down to its constituents and these are used together with the minerals to make new cells and from these, new seeds are formed."

Two misconceptions surface in the justifications under Aspect A: plants breath (respire) CO_2 and plants get their food from the soil. One might assume that some of these students guessed the correct option, and some do not have a full understanding of the process. The lack of link between two concepts (here: plant growth and photosynthesis) is considered by some to be a special kind of misconception (Fisher, Lipson 1986).

A coherent justification, which reflects full understanding, had to refer to the fact that both photosynthesis and materials absorbed from the soil contribute to the added materials

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* In Hebrew the same word is used for "breath" and for "respire".

accumulated during the plant's life. From the distribution in Aspect C for the students who chose the best answer (option 3) it can be seen that only 22% of them established this link in their justifications:

- * "In the process of photosynthesis the plant used these raw materials and converted them into organic substances which were used in the production of new seeds."
- * "The main sources are the water, minerals and CO_2 . From these, in the process of photosynthesis, the plant makes organic substances which build it. The plant grows and produces a new generation - new seeds."

18% referred to photosynthesis as the only source of added organic materials:

- * "By photosynthesis the plant produces organic materials (starch) which is accumulated in the seeds."

52% of the students did not mention the sources of organic matter although some of them did link between CO_2 and photosynthesis as can be seen from the following examples:

- * "The plant needs CO_2 and water for photosynthesis. It also absorbs minerals from the soil."
- * "The seedling needs CO_2 for photosynthesis and without it the seedling cannot reproduce."

The justifications given by students who opted for no. 4 reveal a very persistent and well documented notion about the role of the soil in plant development. Very few of these students (3%) related to photosynthesis in their justification (Aspect A). Most (75%) repeat the wrong idea that plants absorb organic substances from the soil and that these constitute the main source of added organic matter (Aspects B and C):

- * "The seedlings need water, minerals and organic substances. CO_2 and oxygen are also important but they are not a source of materials."
- * "The seedling needs minerals for food, water and organic substances. CO_2 and O_2 are also important but are not major sources for added organic matter as opposed to minerals, water and organic substances."

A typical justification given by a student who chose no. 2 is given below:

- * "The seedling needs food and energy. The food comes from the minerals in the soil. The oxygen is used for respiration."
The findings pertaining to item 2 can be summarised as followed:
1. The justifications reveal the misconception that "plants get the food from the soil in the form of organic compounds." Students who hold this notion are very consistent in using it to explain plant growth.
 2. Students show missing links in their knowledge structure. Some do not link between the process of photosynthesis and the production of organic materials. Others, still, have a more fundamental missing link: they do not link between CO_2 and photosynthesis

ITEM 3

Item 3 (Table 3) required a prediction as to what will happen to an alga cell transferred from fresh water to water with high salt concentration. The process which takes place under these conditions is plasmolysis as a result of osmosis.

Difficulties in understanding osmosis are widely acknowledged and are thought to stem from: abstract nature of the concept (Arnold and Simpson, 1982), deficiency in knowledge of chemistry and physics (Johnstone and Mahmoud, 1980), difficulty in applying knowledge (Arnold and Simpson, 1982), teleological thinking (Friedler, Amir and Tamir, 1986) and from confusion in the use of terms such as "water potential" and

TABLE 3: Descriptive results for item 3 (H-323)

Part A: Distribution of responses (in percentages) to item 3	
IF A SWEET WATER ALGAE WOULD BE TRANSFERRED TO A CONCENTRATED SALT SOLUTION	
Aspects	response (percent)
1. water will go into the cell, until enough pressure is built up to prevent any more water from getting in	7
2. water will go into the cell until the cell bursts	8
3. first, water will leave the cell and then go in again.	4
*4. water will leave the cells and the cell's content will shrink	81

Part B: Distribution (in percentages) of aspects of the justifications.**

Distribution (percent)	
All (H-323)	
A. Description of solute concentration	46
not mentioned	5
wrong: sep more concentrated	10
partial: sep or solution described correctly	41
correct: sep and solution described correctly	
B. Description of water concentration	67
not mentioned	3
wrong: sep has lower water concentration	5
partial: as in aspect A	25
correct: as in aspect A	
C. Cause of water movement	12
not mentioned	12
wrong: salt goes into cell	22
wrong: "aspiration" toward equal concentration	4
wrong: diffusion + "aspiration"	4
wrong: osmosis + "aspiration"	19
correct: concentration or pressure gradient	13
correct: diffusion	14
correct: osmosis	

*correct choice

** Since distribution for the whole sample was very similar to that of the distribution for students who chose option 4 (correct answer) we only give the results for the whole sample.

TABLE 4: Descriptive results for item 4 (H-319)

Part A: Distribution of responses (in percentages) to item 4

IF EGG PROTEIN WOULD BE INJECTED TO THE BLOOD SYSTEM

Aspects	percent response
1. The body will not produce antibodies because it is food	7
2. The body will not produce antibodies because it is not foreign	11
*3. The body will produce antibodies	38
**4. The body will produce specific enzymes which will break it down	44

Part B: Distribution (in percentages) of aspects of the justifications.

Distribution (percent)	
all respondents (H-319)	
A: Egg protein is "foreign"	45
not mentioned	2
wrong: production of antibodies	81
correct: production of antibodies	7
B: Reaction towards foreign protein	55
not mentioned	19
wrong: digestion by enzymes	0
correct: digestion by enzymes	81
C: Reaction toward egg protein	9
not mentioned	8
wrong: production of antibodies	90
correct: production of antibodies	0
D: Cause and effect relationship	31
not mentioned	58
wrong: body is "used" to egg protein	6
Protein is food, digested by enzymes	1
Egg protein has large molecules	64
which need to be broken down	7
Injected protein induces immune reaction	23
	29
	0

* correct choice

**misconception distractor.

"diffusion pressure deficit" (Hutchinson and Sutcliffe, 1985; Gayford, 1984).

Eighty-one percent of the students chose the best answer in this item. Three aspects were identified in the justifications given in this item, and subsequently used in the analysis. The aspects and the distribution of students' responses are given in Table 3.

A coherent justification for the best answer should have specified the difference in solute concentration between cell sap and the surrounding solution and explain the direction and cause of water movement.

Forty-one percent of the students gave a correct description of solute concentration while 44% refrained from doing so altogether.

In agreement with previous findings (Friedler, Amir and Tamir, 1986), the concept of "water concentration" is not available to most students, and only 25% used it to describe the different concentrations (Aspect B).

The source of many of the difficulties in understanding osmosis stems from misconceptions regarding the cause of water movement from one side of the membrane to the other side. This can clearly be seen from the distribution in Aspect C. Thirty percent of the students designated the "aspiration to equalize concentrations" as the cause of water movement. This type of explanation reflects teleological thinking:

- * "The water can leave the cell and it wants to equalize the sweetness and saltiness on both sides."
- * "Because in nature there exists an aspiration to equalize concentrations and therefore water moves by osmosis from a place of lower concentration to a place which is more

concentrated."

Among those students who gave correct causes for water movement 19% said that concentration or pressure gradient was the cause, 14% identified the process of osmosis and 13% diffusion as the cause for water movement:

- * "Because solute concentration in the outside solution is high and there is less water than in the cell, water will move from higher to lower concentration."
- * "This process is called osmosis: water moves from a dilute solution to a more concentrated one and therefore water will get out the algal cell, (which has a dilute solution) and move into the concentrated solution and the cell will shrink."

The question whether giving such answers reflects meaningful understanding of osmosis cannot be answered from these findings. The diversity of explanations (7) found in students justifications suggest that the situation is indeed complex.

ITEM 4

Item 4 dealt with the human body's response to the injection of egg protein directly into the blood system. The item procures the understanding of students of the function of the immune system.

The immune system is studied at the higher grades of high school. We are not aware of any research which has focused on understanding of immunity.

Students' justifications addressed the following aspects:

- A. Egg protein is a "foreign" protein.
- B. The immune system reacts to any "foreign" (non-self) proteins by producing antibodies.
- C. The body's specific reaction towards inject of egg protein.

D. Cause and effect relationship in the body's reaction.

Although it was possible to give a justification by adding: "because egg protein is a foreign protein, when injected into the blood system," most students were more elaborate in their justifications (only 4 gave this concise justification).

The above mentioned aspects as well as the choice, made by the students, on the multiple choice item, were used to identify misconceptions.

All those students who chose options 1, 2 or 4 (62% of total sample) basically held the same notion: injected egg protein is not a foreign substance. This idea led most of them (44%) to predict that the protein will be digested by enzymes.

Table 4 gives the distribution of responses to the four aspects, for the whole sample and for those who chose option 3 (best answer) and 4 (misconception).

It can be seen that category A enables us to identify 3 groups of students.

I. Those who indicated that injected egg protein is foreign (34%). Most of them came from amongst those who chose the best answer.

II. Those who indicated that injected egg protein is not foreign (21%). This group came mainly from amongst those who have chosen option 2 and option 4.

III. Those who did not mention whether or not the injected protein was foreign. This group came mainly from amongst the students who chose option 4.

Further analysis revealed the following (Fig. 1): Group I shows a coherent and consistent line of thought; most of them gave correct statements in both aspects B and C:

immune system can distinguish between proteins which are harmless food from proteins which are not food (or harmful).

- * "As soon as a foreign substance is injected to the blood, antibodies are produced. Egg protein is not part of our body and therefore it is foreign. The body does not distinguish foreign material which is food from foreign material which is not food."

Group II shows the existence of missing link in their knowledge structure; on the one hand they know that egg protein is digested by enzymes. Half of them also stated that antibodies react against foreign proteins. Their missing link is in understanding that injected proteins lead to a response which is different from the response to "eaten" protein. They hold that the response of the body is determined by the fact that egg protein is "food," or by the fact that it has large molecules which cannot enter the cells unless broken down:

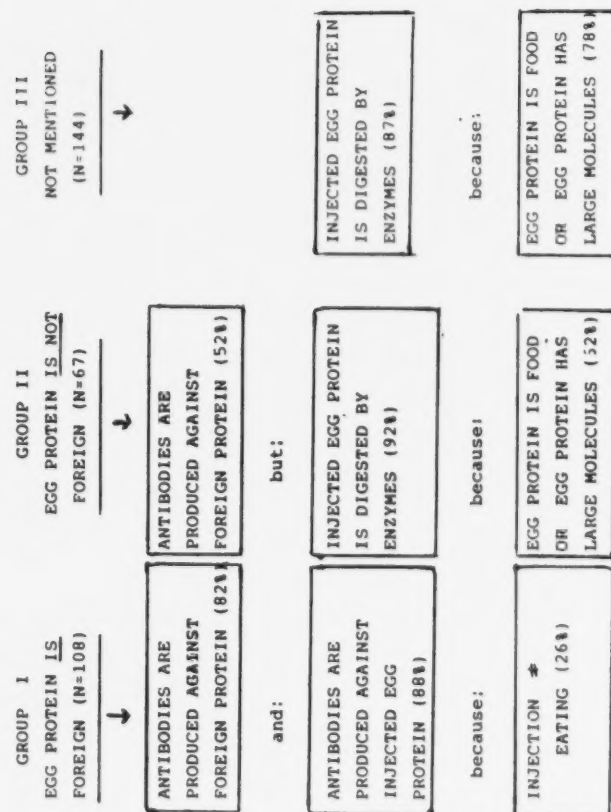
- * "The body will not produce antibodies against egg protein because it is harmless food. The body produces antibodies only against antigens which can cause illness."
- * "(The body will produce enzymes) in order to digest it. Antibodies fight only bacteria but not proteins."

Group III which comes mainly from amongst those who chose option 4 reveal no knowledge about the immune system. Their justifications include repetition of the option itself, and a few elaborations explaining the function of enzymes:

- * "Egg protein is broken down into amino acids. Each amino acid is equal to three nucleotide bases. The breakdown is done by enzymes in the stomach and it is absorbed in the intestine. Each enzyme has its specific substrate."

The findings described here also point to misconceptions regarding the function of two distinct systems: the immune system and the digestive system. Thus some students believe that materials can be digested in the blood system and others that the

FIGURE 1: COMPARISON OF CONTENT OF JUSTIFICATIONS GIVEN BY GROUPS OF STUDENTS ACCORDING TO THE IDENTIFICATION OF THE EGG PROTEIN AS "FOREIGN" OR AS "NOT FOREIGN"



CONCLUSIONS AND IMPLICATION

The results presented here show the effectiveness of justifications to multiple choice items in uncovering misconceptions of students. They also point to the gap which sometimes exists between the degree of understanding as revealed by the choice of the best answer and the understanding, as exhibited in the justifications to that answer. Carefully constructed multiple choice items are by themselves efficient in corroborating our knowledge about existing misconceptions, like item 2 or item 4. Their main function can be a means to determine the frequency of known misconceptions among certain populations of students.

The contribution of the justifications is two fold:

1. Identifying misconceptions, missing links and teleological thinking among students who are successful in choosing the best answer.
2. Achieving better understanding of notions held by students who choose the distractors, and identifying their misconceptions.

Thus we have shown that although a large group of students chose the correct answer in item 1, many of them reveal misunderstandings of Mendel's Laws. A similar situation existed among the students who chose the best answer in item 2 as evidenced by the fact that about $\frac{1}{4}$ of them did not mention the process of photosynthesis.

In item 3 it was shown that students had suggested many alternative explanations to the cause of water movement. Some of these explanations were correct, others were incorrect. However the relative frequency of each could not be deduced just from the percentages of correct answers, which was relatively high, and the analysis of justifications contributed significantly to our knowledge on this issue.

A different situation was discovered in the justifications

for item 4. Here it was found out that many of the students who had chosen incorrect answers did so because their knowledge was only partial. They did possess and express some relevant correct segments of knowledge about the immune system but could not apply it correctly to a somewhat tricky situation - egg protein injected into the blood.

The justifications given by students who had chosen distractors were especially revealing as regards to misconceptions. This is best seen in the justifications for item 2, option 4. As found in many other studies, our study shows that about a quarter of the students in the sample hold the notion that the plant gets its food from the soil and use this notion in a very consistent manner.

A major implication of our study relates to the important contribution that justifications to multiple choice items can make. A requirement to justify select multiple choice items can be of great help to the teacher in learning more about the actual depth of understanding of his/her students and in uncovering their misconceptions. In order to make the best use of the potential of justifications, care should be taken in selecting appropriate multiple choice items for this purpose. One criterion for selecting such items is the inclusion of known or conjectured misconceptions as distractors.

REFERENCES

- Arnold, B., Simpson, M. (1982). Concept development and diagnostic testing - Osmosis in "O" level biology. Aberdeen College of Education. Aberdeen, Scotland.
- Barker, M. (1985). Teaching and learning about photosynthesis. Working papers no. 220-229. Science Education Research Unit. University of Waikato, Hamilton, New Zealand.
- Bell, B. (1985). Students' ideas about plant nutrition: What are they? Journal of Biological Education, 19:213-219.
- Brumby, M. (1979). Problems in learning the concept of natural selection. Journal of Biological Education, 13:119-122.
- Friedler, Y., Amir, R., Tamir, P. (1986). High school students' difficulties in understanding osmosis. A paper presented at NARST meeting, San Francisco, CA.
- Fisher, K.M., Lipson, J.I. (1986). Twenty questions about student errors. Journal of Research in Science Teaching, 23:783-805.
- Gayford, C.G. (1984). Water relation and vacuolated plant cell: A brief study of the topic at A-level in school biology. Journal of Biological Education, 18: 151-155.
- Gilbert, T.K., Osborne, R.T., Fensham, P.T. (1982). Childrens' science and its consequences for teaching. Science Education, 66:623-633.
- Hackling, M.W., Treagust, D. (1984). Research data necessary for meaningful review of grade ten high school genetics curricula. Journal of Research in Science Teaching, 21:197-209.
- Hutchinson, C.H., Sutcliffe, J.F. (1983). An approach to the teaching of cell water relations in biology at A-level using the water potential concept. Journal of Biological Education, 17:123-130.

- Johnstone, A.H., Mahmoud, N.A. (1980). Pupils' problems with water potential. Journal of Biological Education, 14:325-328.
- Londgen, B. (1982). Genetics - Are there inherent learning difficulties? Journal of Biological Education, 16:135-140.
- Murray, D.L. (1983). Misconceptions of osmosis, in: (Helm and Novak, Eds.) International Seminar on Misconceptions in Science and Mathematics. Cornell University, Ithaca, NY (pp. 427-433).
- Nussbaum, J. (1979). Children's conceptions of earth as a cosmic body: A cross age study. Science Education, 63:83-93.
- Nussbaum, J., Novick, S. (1982). Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy. Instructional Science, 11:183-200.
- Peterson, R., Treagust, D., Garnett, P. (1986). Identification of secondary students' misconceptions of covalent bonding and structure concepts using a diagnostic instrument. Research in Science Education, 26:40-48.
- Simpson, M., Arnold, B. (1980). An investigation of the development of the concept of photosynthesis to S.C.E. "O" grade. Aberdeen College Education. Aberdeen, Scotland.
- Smith, E.L., Lott, G.W. (1983). Teaching for conceptual change: Some ways to go wrong, in: (Helm and Novak, Eds.) International Seminar on Misconceptions in Science and Mathematics. Cornell University, Ithaca, NY (pp. 57-66).
- Smith E.L., Anderson, C.W. (1984). Plants as producers: A case study of elementary science teaching. Journal of Research in Science Teaching, 21:685-698.
- Staver, J.R. (1986). The effects of problem format, number of independent variables and their interaction on student performance on a control of variables reasoning problem. Journal of Research in Science Teaching, 23:533-542.
- Stavi, R., Eisen, Y., Yaakobi, D. (1987). How Israeli students aged 13-25 understand photosynthesis. International Journal of Science Education, 9:105-115.
- Stewart, J.H. (1982). Difficulties experienced by high school students when learning basic Mendelian genetics. The American Biology Teacher, 44:80-83, 89.
- Tobin, K.G., Capie, W. (1981). The development and validation of a group test of logical thinking. Educational and Psychological Measurement, 11:413-423.
- Tolman, R.R. (1982). Difficulties in genetic problem solving. The American Biology Teacher, 44:252-257.
- Treagust, D.F., Haslam, F. (1986). Evaluating secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier diagnostic instrument. A paper presented at the NARST meeting, San Francisco, CA.
- Wandersee, J.H. (1983). Students' misconceptions about photosynthesis: A cross age study, in: (Helm and Novak, Eds.) International Seminar on Misconceptions in Science and Mathematics. Cornell University, Ithaca, NY (pp. 441-463).

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Introduction

This problem was investigated by Staver (1986), in this paper and in view of his earlier results (Staver, 1984; Staver and Pesiarella (1984), he states that the influence of the testing is only marginally significant. An effect was found only in problems indicated by him as difficult. Staver (1984) studied the ability of the participants to apply formal logic in the forms of proportional thinking and variable controlling. Concerning operative knowledge (Lawson, 1982; Lawson, 1985) it can be assumed that when the child reaches the stage when he is able to solve the problem correctly using his own logic, he can do it in all testing conditions. He can then contradict the wrong suggestions included in the multichoice test. This is not the case when the qualitative explanations and views that people have about physical concepts or natural phenomena are checked. In this situation the participant is not sure that he really knows the right answer. In many times he is only guessing. The situation is more ambiguous, as knowledge, as well as logic, is involved in choosing the right answer. Thus when the participant is confronted with the diversions of the multichoice test he can be tempted to prefer the choice of the wrong answer. Especially if the wrong diversion contains scientific terminology, learned but not fully understood. In this situation the participants cannot reject the wrong answer, since they do not have enough knowledge. Thus, in the studies of the qualitative views about nature test format becomes important, and might have a significant effect on the distribution of the results.

Different testing methods have been used in previous research. To enable the comparison of the results of various researches to each other the effect of the testing methods should be checked.

In this study three kinds of testing methods were used. An individual oral test, a multichoice test and an open ended written test. Carrying out all these kinds of tests enabled us to perform the task of

finding out the effect of testing format on the distribution of the results. The subject that was included in these tests was children's ideas concerning boiling and evaporation.

MethodDesign and tests

This investigation was carried out in three phases.

Phase One

In phase one the oral individual testing method (Piaget, 1929; Piaget, 1972) was used. This method is the only one considered suitable for testing young children, up to the age of nine (Bar, 1987a; Brainerd, 1974). The age range observed during this phase was five to twelve years, the number of participants was eighty-three (see figure 1) with equal numbers of boys and girls. The participants came from a city and are of a middle class background. The test was presented in the form of a dialogue. Each participant was presented with boiling water and was asked to describe his observations. Then he/she was asked: what is the vapour made of? what will happen to the quantity of water? where does the vapour come from? and can vapour be changed again into water. Concerning evaporation they were asked what happens to water that was spilled on the floor, and where can this water be found.

Phase Two

During this phase five multichoice problems were presented in the following order:

1. Wet laundry was hung on the rope, it became dry. The water:
 - a. Went into the sun
 - b. Is in the laundry
 - c. Changed into air and disappeared
 - d. Changed into hydrogen and oxygen
 - e. Changed its form and is scattered in the air
2. Water was spilled on the floor, the floor became dry. The water:
 - a. Disappeared
 - b. Penetrated the floor
 - c. Is scattered in the air of the room
 - d. Can be found near the ceiling

3. Can vapour be changed into water?
 - a. Yes, since vapour is another form of water
 - b. No, water just changed into air and disappeared
 - c. Vapour can change into water only in the clouds
 - d. This happens only during winter when it rains
4. A wet saucer was left on the table, it became dry. The water is now:
 - a. In the saucer
 - b. Changed into air and disappeared
 - c. Changed into hydrogen and oxygen
 - d. Just changed its form and scattered into the air
5. When water is boiled, vapour appears. The vapour is made of
 - a. Water
 - b. Air
 - c. Hot air
 - d. Heat and water
 - e. Hydrogen and oxygen

The diversions of the problems were taken from the answers collected during phase one, and earlier investigations. Za'rour (1976) investigated the "drying of the laundry" and Osborne and Cosgrove (1983) investigated the "drying of the saucer." The age range of this phase was between ten to fourteen. Other details of sample and population are similar to those of phase one. The numbers of participants in each age group is given in figures 2 to 5. One age group participated in phase one as well as in phase two, thus enabling us to check the influence of the test format on the results.

Phase Three

During phase three the same problems represented at the same order as in phase two were presented, but in an open ended form. The age range and population were as in phase two. The number of participants was two hundred and forty, sixty at each age group. Thus we were able to check if the differences recorded are solely due to the difference between the open and closed tests or that they may be due to effects of the a) age range and population, b) the context or c) the difference between an oral or a written test.

Results

Phase One

The results of phase one are given in fig. 1, and can be summed up as follows:

The understanding of boiling precedes this of evaporation and condensation. In all the age groups examined, during phase one, about fifty percent or more of the participants said that when water is boiled vapour is initiated, this vapour is made of water, the quantity of water is reduced and the vapour is coming from the water (figure 1, B, C, D and E).

The understanding of evaporation and condensation as a function of age are parallel to each other (fig. 1 A and F). The percentage of correct answers for these items reaches 60 at most, and is smaller than the percentages of correct answers recorded for all the problems of boiling at all the age groups.

Phase Two

In this phase the evaporation problem was presented through three contexts. The distribution of the results concerning the problem of the drying of the floor is given in fig. 2. It is similar to that of phase one. Figure 2 shows that the percentages of correct answers in the age group that participated in both phases are similar. The diversions did not distract the participants since they are typical to younger age groups and represent only minor views at the age range ten to fourteen (Bar, 1987b). The percentage of correct answers reaches 82 at the age of fourteen. The effect of the diversions is demonstrated though in fig. 3, where the distribution of the answers given to the problem of the drying of the laundry is shown. The percentage of correct choices was reduced considerably and it reaches only 30% at the oldest age group, only 40% at 12.5 years (fig. 3, E). Instead the diversion that says that during evaporation the water changes into hydrogen and oxygen was frequently chosen (Fig. 3, D). This answer was recorded only once during phase one. This result shows that the participants are not really sure that water vapour is another form of water. Even in the open ended test many of them say that the vapour consists of air. The idea that during evaporation the water molecule disintegrates into hydrogen and oxygen is hardly found in the oral test, but was oftenly

recorded during phase two, this result demonstrates the effect of the testing method. In fig. 4 the views concerning the problems of the "drying of the saucer" are given. According to the order of the test this problem was solved after the problem of the "drying of the floor" (fig. 2) and the possibility of changing vapour into water were already solved (fig. 6). Comparing the results given in figure 3 and figure 4 we see that the percentage of correct answers appearing in figure 4 is twice as much as in figure 3. But even then the percentages of the answer "hydrogen and oxygen" are rather high and exceed considerably this of the oral test (as mentioned above it was recorded only once), demonstrating again the effect of the testing.

The clear conclusion of phase one, that the understanding of boiling precedes this of evaporation was not recorded in phase two. When confronted with the possibilities that when water boils it changes into hot air, or to water and heat, the percentage of correct answers reduced from 73 to 36 at the age group eleven and five months (fig. 5). The percentage of correct answers grows as a function of age and reaches 58 percent at the age of fourteen but even then it is less than the percentages recorded in phase one. The misconceptions heat or hot air were recorded occasionally also in phase one, but only a few answers of this kind were found and their percentage in the whole sample is less than three. Again the effect of the format is very apparent.

In figure 6 the distribution of the results concerning the problem of condensation is given. The distribution of the results is similar to that of phase one and to the percentage of correct answers to the problem of the drying of the floor (figure 2). This demonstrates again the result of phase one that the development of the understanding of evaporation and condensation are parallel to each other.

The results of phase three were similar to those of phase one. Phase three probed the same contexts as phase two, at the same age range as in phase two and more over it was a written test as in phase two. In spite of all this the results of phase three are the same as those of phase one and not as those of phase two.

Concluding Remarks

The results of these investigations show that when qualitative problems checking children's understanding of physical concepts are studied, the format of testing is significant. Misconceptions that are hardly found in the open ended tests, oral, as well as, written are recorded in considerably high percentages in the multichoice test. It is worthwhile to mention that when our participants, were presented by similar problems, in the same format, and using the same diversions, as in earlier investigations, our results were similar to those appearing in those earlier studies. Thus the effect of the test format and the choice of the diversions should be taken into account while referring to previous results also.

Though the same views were recorded in the open ended tests and in the multichoice test their distribution was changed considerably. Many participants are drawn to the "scientific" suggestions and prefer them above the right answers that they would have given in an open ended situation. The same thing may happen, also, in the class. When learning chemistry and being exposed to the concepts of hydrogen and oxygen the same mistakes that were recorded in the multichoice test can occur. The pupils may change their ideas from the correct one, to the wrong idea that during evaporation the water changes into hydrogen and oxygen. Another misconception is the idea that energy has some material meaning. It occurs also sometimes in the open ended situation. But the frequency of this view is very much enhanced when it is presented in the multichoice test.

There is some difference between the misconceptions that appear concerning the various concepts. In the boiling problem the idea of heat is more self-suggested, thus the misconception "hydrogen and oxygen" is less frequently recorded. This misconception is more abundant with regard to the problems of evaporation.

While teaching science it is recommended to pay attention to these findings which indicate that the pupils tend to misinterpret scientific concepts and processes and use them wrongly (see also Osborne and Cosgrove 1983). The effect of the testing format shows that even those who give right answers in open ended tests and in the class are not sure about the correctness of their own answers, as they can be misled even by a diversion in a multichoice test.

Reference List

- Bar, V. (1987a). The development of ratio concepts in two content domains Science Education, in press.
- Bar, V. (1987b). The development of the concept of evaporation. Submitted for publication: Journal of Research in Science Teaching.
- Brainerd, C.J. (1974). Training and transfer of transitivity conservation and class inclusion. Child Development, 45, 324-335.
- Lawson, A.E. (1982). The reality of general cognitive operation. Science Education, 66(2), 229-240.
- Lawson, A.E. (1985). A review of research of formal reasoning and science teaching. Journal of Research in Science Teaching, 22(7), 569-617.
- Osborne, R.J. and Cosgrove, M.R. (1983). Children's conceptions of the change of state of water. Journal of Research in Science Teaching, 20(9), 825-838.
- Staver, J.R. (1984). Effects of method and format on subjects' responses to a control of variable reasoning problem. Journal of Research in Science Teaching, 21(5), 517-526.
- Staver, J.R. (1986). The effect of problem format, number of independent variables and their interaction of students' performance on a control of variable reasoning problems. Journal of Research in Science Teaching, 23(6), 533-542.
- Staver, J.R. and Pesiarella, E.T. (1984). The effect of method and format on the response of subjects to a Piagetian reasoning problem. Journal of Research in Science Teaching, 21(3), 305-314.

Figure Captions

Figure One - The development of the conceptions of Boiling, Evaporation and Condensation

Evaporation

- A. Percentage of correct answers to the problem of the drying of the floor

Boiling. Percentages of answers given to the following items:

- B. When water is boiled vapour is seen, this vapour is "coming from the vessel."
- C. The vapour is coming out of the water.
- D. The quantity of water is reduced
- E. The vapour is made of water

Condensation

- F. Percentage of correct answers to the problem "Can vapour change into water?"

Figure Two - the drying of the floor

- A. The water disappeared
- B. The water penetrated the floor
- C. The water changed form and is scattered in the air.
- D. The water is near the ceiling

Figure Three - The drying of the laundry

- A. The water is in the sun
- B. The water is within the laundry
- C. The water changed into air and disappeared
- D. The water changed to hydrogen and oxygen
- E. The water changed its form and scattered in the air

Figure Four - The drying of the saucer

- A. The water entered into the saucer
- B. The water changed into air and disappeared
- C. The water changed to hydrogen and oxygen
- D. The water changed its form and scattered in the air

Figure Five - The vapour coming from boiling water is made of

- A. Another form of water
- B. Air
- C. Hot air
- D. Water and heat
- E. Hydrogen and oxygen

Figure Six - Can vapour be changed into water?

- A. Yes, because vapour is made of water
- B. No, because the water changed into air and disappeared
- C. Vapour changes into water only in the clouds
- D. Vapour changes into water only in winter when it rains

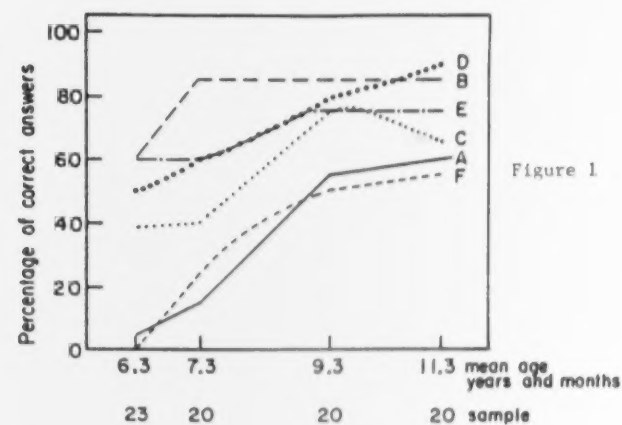


Figure 1

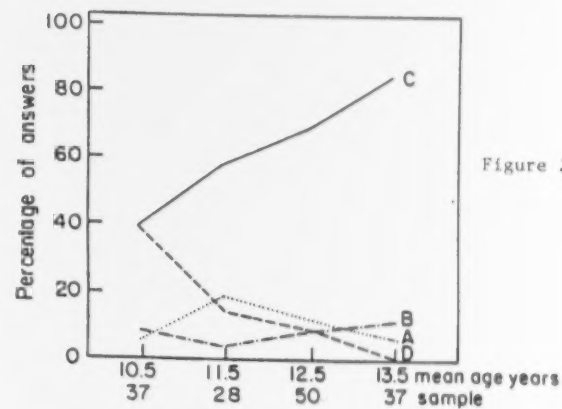


Figure 2

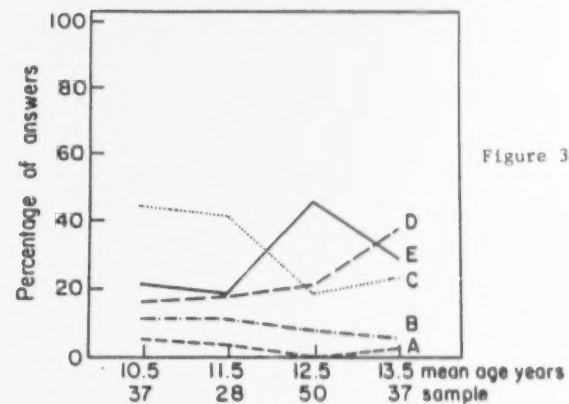


Figure 3

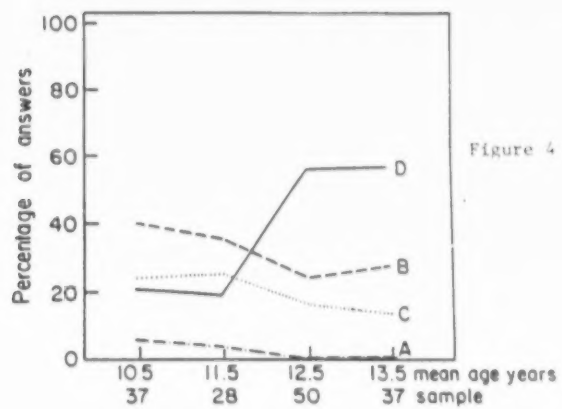


Figure 4

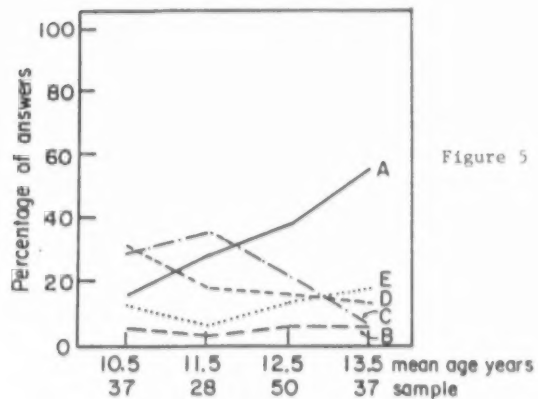


Figure 5

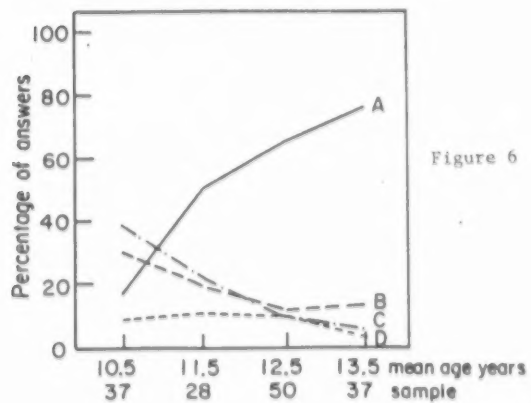


Figure 6

THE DESIGN, IMPLEMENTATION AND EVALUATION OF A
MICROBIOLOGY COURSE WITH SPECIAL REFERENCE
TO MISCONCEPTION AND CONCEPT MAPS

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Introduction

Ausubel's learning theory (Ausubel 1968 and Ausubel et al 1978), is based on the assumption that human thinking involves concepts. He further postulates that a hierarchical structure of concepts is an important variable in students' learning. One of the most important distinctions in Ausubel's theory is between rote learning, and meaningful learning. Meaningful learning according to Ausubel's theory depends upon the idiosyncratic concepts the individual holds. For Novak's (1979) theory of school learning, concepts and the propositions describing relationships among them, are also of primary importance.

The design of concept maps, is described by Novak as: "A process that involves the identification of concepts in a body of study materials, and the organization of those concepts into hierarchical arrangement from the most general, most inclusive concepts to the least general, least specific concepts" (Novak 1981 p. 3).

Ferry (1986) claims that a brain needs to compare new information with what it already knows, and the best way to store information is in modifiable networks.

Following Hertig's (1976) call to biology educators and learning theorists, to combine their talents, to improve the quality of biology education, Stewart et al (1979), demonstrates how concept maps (C.M.) can be used in biological curriculum planning, instruction and evaluation.

Concept maps were used as instructional aids as well as for course design examples: In earth science Ault (1985), in mathematics Malones and Dekker (1984), in physics Moriera (1978) in biology Novak (1979), Stewart et al (1979), and Novak and Symington (1982).

There are several different styles and procedures as to the way concept maps are designed and evaluated which indicates how widely maps are used (e.g. Matthews 1984, Novak 1979, Cronin et al 1982, and Stuart 1985).

C.M. as an investigating tool of meaningful learning was used by Novak (1979), Edwards and Fraser (1983), and Brumby (1983).

They were employed at different age levels with various ethnic groups, Leman et al (1985) including junior high school Novak et al (1983), senior high school Gurley (1982), and college students Arnaudin et al, and Moriera (1979).

Reading and remedial reading is another area of research which has used concept maps. Since educators and reading experts agree on the importance of the organization of texts and other learning materials, as a factor in comprehension and in facilitating memory. Berkowitz (1985), compared experimental methods of content organization in the teaching of reading to sixth grade students. She found that the group of students who constructed maps scored significantly higher than the other groups.

Brooks et al (1983), based their research on Anderson's "Schema theory." They found that students trained in the use of schema, significantly facilitated their recall of scientific text. Camperell et al (1985). Showed the use of "network diagrams," which are very similar to concept maps, as a tool for teaching remedial reading. These maps or network diagrams were more helpful than outlines.

According to Spiro and Taylor (1980), Anderson (1983) and Meyer et al (1984), readers who are sensitive to text structure appear to recall more information than others. They believe that if students identify the structure of the learning materials their recall may be enhanced. All these findings seem to support the learning theory of Ausubel and Novak (1978) and its implications for science education.

Another aspect in science learning, which concerns science educators are the large number of misconceptions, which were identified in all areas of science, those seem to interfere with proper learning. For examples see Helm and Novak (1983).

In our study special emphasis was drawn to identification of learning problems and misconceptions, while designing our learning program. The program was designed hierarchically, and concept maps were used as a main heuristic device through all stages of research, from planning and designing of the learning program, through instruction and evaluation.

Material and methods

This study reports the development of a microbiology course based on Ausubel and Novak's learning theory (1978). It's implementation and evaluation in the classroom.

The main characteristics of the developed curriculum were:

- a) Enhancing meaningful learning by exposing students to hierarchically organized learning material. (From general ideas through concepts to details and examples).
- b) Identifying learning problems and misconceptions, and referring to them in the program.
- c) Using concept maps (C.M.) as a basic strategy through all stages of planning, designing, implementation in the classroom, and students' evaluation.
- d) Updating the subject matter with current conception of microbiology.

Our work was carried out in few stages:

Preparatory stage - This stage included:

Collected information on existing learning materials, in microbiology, for high school students in Israel - It was found, in the years 1979-1980, that most microbiology courses were using the Hebrew version of the B.S.C.S. (Yellow version text) as published about 20 years ago.

Identifying learning needs - Was accomplished by: Talking to teachers, visiting classrooms, reviewing science education journals, reviewing study programs, local and foreign. It was found that microbiology had been taught in Israeli schools in tenth or eleventh grade, and sometimes in twelfth grade. Time devoted to the subject ranged from several weeks to several months.

Updating the subject matter - Was accomplished through current scientific literature and discussions with microbiologists.

Identifying new scientific knowledge that is relevant to education.

In science education journals we found examples of such knowledge. For example: The newly established primary kingdom of organisms, the "archabacteria" Evans (1983), Lennox (1983); previously unknown diseases Sobieski (1984), and the importance of taxonomy in biology education Honey et al (1986).

Identifying learning problems and misconception - was carried out during the preparatory stage, as well as through all other stages of the research.

The sources of this information were: science education literature, results of the matriculation examination (those are the final examinations given to high school majors), classroom observation, students concept map, and various tests we administered in some high school classes.

We concluded from the Preparatory stage that:

1. There is a need for an up-dated learning program in microbiology.

2. This program should be modular, so that it may be adapted for different students' levels, and different lengths of time.
3. Special attention should be given to learning problems and misconception.

Developing the learning program

Based on those conclusions the program was developed, Table 1 summarizes the three stages of the development.

In all the stages informal classroom observations were made, as well as collecting students' written work such as: examination papers, and concept maps.

Table 1: Developing stages of the learning program, and their main characteristics.

Developing stage	Characteristics	No. of units developed	No. of classes studying
Pilot	- First experience with C.M. a. As part of programs text b. As part of student's work - Many ready made C.M. were included in the text - Identifying learning problems	one	one
Formative	- Longer exposure to C.M. exper. - Less ready made maps in text - More student's prepared maps - Considering learning problems already detected	5 modular	5
Summative	- C.M. became an integral part of the program - More learning problems were treated.	8 modular	16

Since we'll report in this paper mainly the results obtained at the summative stage, classroom procedure and students evaluation will be described for this stage.

Classroom procedure

At the summative stage 16 classes participated. 10th 11th and 12th grades, in this report no distinction was made between the different grades). The classes were divided into 3 groups:

1. "Mappers" - map instructed group "mappers" who studied our learning program and worked with C.M.
2. "No maps" - this group studied the program, but was not required to construct C.M. "no maps."
3. "Comparison" - this group studied the B.S.C.S. curriculum without mapping exercise.

Students' evaluation

Students' evaluation through all stages of this study was based on paper and pencil exams, including several types of examination items, for details see Table 2.

Mapping strategies

Two main types of concept maps were used during this study:

1. Ready made C.M. which were an integral part of the text.
2. Students' constructed C.M. of the following types:
 Partial maps - had to be completed, maps that had to be constructed following a supplied list of relevant concepts and finally maps that had to be constructed from students own fund of knowledge (see also Table 1).

Introducing maps

This was done in three different variations at each stage:
 Pilot stage - Students got an example of a ready made C.M. Then they obtained a list of microbiological concepts, which they were asked to organize into a C.M, similar to the example given.
 Formative stage - In this stage, the "mappers" were introduced to a modification of Novak's "Learning how to learn" (1981) exercise.
 Summative stage - The introduction to C.M. is included in the preface

to the program's textbook. It is composed of: A short explanation about the importance of knowledge organization, an example of a C.M. summarizing a short text, and instructions for self assembly of C.M., also summarizing a short text.

Students' attitude toward C.M. and the learning program

The procedure in which attitudes were assessed are summarized in Table 3.

Teachers'* involvement in the learning program

Pilot stage - No direct teacher involvement was required at this stage.

Formative stage - The biology teachers taught the subject matter, while introduced the C.M.

Summative stage - Teachers taught the subject matter, as well as C.M. according to the introduction of the program.

Table 2 pretest and posttest procedure

pretest	posttest
concept definitions	
self-evaluation of concept understanding	
multiple choice questions	
open-ended questions	
	"reasons" to multiple choice answers C.M. for "mappers," openended for others, attitude questionnaires

*We like to thank all the teachers and students who participated in this study for their cooperation

Teachers were asked to write a report about the course procedures, and to answer an attitude questionnaire, about the program and working with C.M.

Table 3: Students' attitude evaluation in the various stages of study

Stage of study	attitude assessment
pilot	oral discussion with students
formative	short questionnaire about the, text, one general question about C.M.
summative	more detailed questions* about both text and maps also questions comparing mapping to other learning methods.

*A modification of Arnaudin et al (1984) attitude questionnaire

Results

We differentiated between two main types of misconceptions: 1. general principles and 2. related to specific concepts.

1. General principles

Many students do not understand the role that microorganisms play in nature, their role in material cycles, especially as decomposers, and their importance to mankind. This was first revealed in answers given in matriculation examinations.

Following these findings, the same questions that were asked in the matriculation exams, were asked in our pretests (Table 4). In the pretest only 15% of students could explain the role of microorganisms in nature as, in food webs, and in different material cycles ("complete" answer Table 4), 44% gave partial answers, ("partial") and 41% thought that microorganisms were either harmful

or else unimportant ("wrong answer"). Even a larger number of students couldn't explain the importance of microorganisms to humans: for example none of the students mentioned the natural microflora of our bodies ("complete answer"). About 30%, if given the choice, would have eliminated bacteria and other microorganisms from Earth ("wrong answer"). 3% of students had, stated that any creature which God or Nature have created has it's place on Earth and shouldn't be extinguished ("God's creation").

Other basic misconceptions were revealed when students had to explain the biological principles of food preservation. They failed to understand that in order to preserve food we create conditions which are not favorable for microorganisms, by changing one or more of the basic conditions of life, such as temperature, or water supply. The answers showed that less than 15% gave a full explanation to those questions ("complete answer," see table 4).

2. Specific concepts

Antibody - in the pretest only 7% were able to define this concept ("complete answer," table 5). Results of a multiple choice question in the matriculation examination, showed 58% of correct answers, and 14% in our pretest, to questions related to the nature of antibiotics (Table 6).

Antibiotics - only 3% wrote in the pretest a complete definition of antibiotics ("complete answer"). Common misconceptions were: "Antibiotics do help antibodies* fight bacteria," or "antibiotics combine with antibodies and behave like one" ("wrong" and "confused with antibody" answers table 5).

Students were also asked: "How is resistance against antibiotics developed? and what is it's medical importance?" These questions were asked at matriculation exams, and in our

*In Hebrew the concepts antibiotics and antibodies sound different than in English so there is no question of semantic confusion.

questionnaires. In the pretest 19% (multiple choice question) chose the right answer ("complete answers" table 6), 31% thought that bacteria develops antibodies against antibiotics, this was true also for 27% of answers to matriculation exams, 24% of the students in the pretest thought that "the human body develops resistance against the antibiotics."

Some misconceptions were particularly uncovered in C.M. prepared by students. Examples: Inability to differentiate between prevention and curing of diseases and misunderstanding of Koch's postulates (Exhibit 6). Misunderstanding of material cycles in nature is another example.

Some misconceptions were mainly uncovered during classroom observations, example:

"The role of water in maintaining life" - The question rose while discussing what are the growth needs of bacteria. Water is a basic requirement for every form of life. It turned out that for many students in the five classrooms we observed this was not clear. Similarly, many students did not understand the importance of other basic substances such as carbon and nitrogen.

Multiple choice questions were yet another source to uncover misconceptions (see table 6).

Dealing with misconceptions in the learning program, and its effect on students posttest results

While developing the learning program, special emphasis was given to the topics and concepts in which learning difficulties were identified.

We'll describe how some of those topics were treated in our program, for example: "The importance of microorganisms in nature, and to men." We prepared a C.M. summarizing this subject.

This C.M. served as a guide for developing the first chapter of our book. This map is not included in the book. However students "mappers" were asked to summarize this chapter in the form of a C.M. The maps produced turned out to be very clear, and meaningful (Exhibit 4). This was also one of the main subjects included in students final maps. Answers to the questions in the posttest compared to the pretest (see Tables 4, 5, and 6), showed a big improvement in the groups that participated in our learning program. The comparison group didn't do as well. There also seems to be a tendency of "mappers" to score somewhat higher on those items.

"The essentials of life maintenance, and the biological principles of food preservation." In the learning program the essentials of maintaining life was explained in the second chapter, later in chapter 7 application of these principles were explained, as the basis for food preservation.

The questions about food preservation in the posttest were identical to those given in the pretest. Students' answers (Table 4) showed improvement, compared to the pretests, although not as much as we had hoped for. As with the previous items, students working with our program scored higher than comparison students.

Similar treatment was given to other misconceptions, mentioned earlier, antibodies and antibiotics. In order to improve understanding of those concepts, students were required to compare between them. As a suggested treatment for the "distinction, between prevention and curing of disease," students were asked to draw a C.M. For posttests results see Table 5.

Again test groups scored higher than the comparison, and "mappers" show a tendency to score somewhat higher than the others.

Similar results are obtained with multiple choice questions (see Table 6).

Working with concept maps

C.M. were used throughout the whole program, for various purposes: The first map (Exhibit 1) presents the overall idea of the course. Exhibit 2 is an example of a map that summarizes a large body of knowledge, as introduced in the pilot unit.

Examples of well designed maps prepared by students are Exhibits 4 and 5. A C.M. summarizing one defined subject or the main features of the course (Exhibit 3).

Students were encouraged to add relevant concepts, of their own knowledge, while designing maps with the help of a concept list. Exhibit 5 is an example of such a map. This kind of map also helped us understand how newly acquired concepts are integrated in students' mind.

Exhibit 6, reveals misunderstanding of Koch's postulates and in complete understanding of prevention and curing of disease.

Exhibit 7 is a teacher's prepared map, for instruction design.

Attitudes toward C.M.

It is quite clear, from students answers, (on a Likert scale questionnaire), that Novak's main ideas about C.M., as an heuristic devise, are understood by many of the students who studied with them, as an integral part, of the learning program. Between 40%-60% thought it is a very good method, about 40% were uncertain, and between 20%-30% didn't like it. C.M. scored the highest compared with three other learning activities namely: Answering questions, reading scientific papers, or organizing information (Table 7) as a means for understanding of concepts, understanding their the relationships and hierarchy. More than one-third thought that C.M. are a good way to study biology (Table 8) but only 7% thought they might use them in other subjects, about 40% thought that C.M. reflect well their knowledge in a certain subject, and helped them

in arranging their concepts meaningfully. Only 20% thought that maps help in uncovering misconceptions. Only 8% thought that concept-mapping is a pleasant activity, and only 5% like to discuss their maps with friends. Most of the students thought that mapping is neither difficult nor a waste of time. For more details see Table 8.

In answers to an openended question that students indicated, C.M. were a suitable way to study the following subjects: Microbiology, biology, social science, sciences. And to the question "to what ways do you think maps can be of help," 55% answered that it is very useful in organizing learning materials, 16% thought it might be helpful sometimes, 21% stated that mapping is a pleasant activity but not useful, and 8% thought it was not useful at all (Table 8).

Students' comments about working with C.M. revealed substantial variability in their attitudes. For example one of the students even though her maps were excellent, stated: "I think preparing maps is a waste of time, I would rather get prepared ones." Another good mapper said: "preparing maps help me remember learning materials, but it isn't fun studying in this way." Several students thought that: "Mapping is difficult or a total waste of time." Another student on the other hand felt that, "mapping made learning more exciting." And still another said "maps are very helpful." Some students stated that their attitude toward mapping changed with experience. First they thought mapping is just some extra unnecessary work, but later with more experience they had come to realize that maps are very helpful.

The experience C.M. had some additional effects. There are some students who prepared maps on subjects other than biology. Others who voluntarily prepared maps in the microbiology course, even when other ways of summarizing had been suggested.

One student who suffers cerebral damages, and has some motoric and learning difficulties, found mapping extremely beneficial.

Some culturally deprived students, found working with maps helpful and rewarding.

Some of the teachers who worked with us started planning their own classroom instructions with the help of maps not only in microbiology but in other biological subjects, like ecology and genetics as well (see Exhibit 7).

In classrooms where teachers were favorable toward mapping, their attitude was reflected in the quality of maps drawn by their students, as well as their attitude. The attitude of students of two such teachers compared with the whole population of mappers, show higher scoring on most items (see Table 7).

Those teachers also stated that C.M. were an excellent tool for them to discover misconceptions of their students.

Attitudes toward the learning program

Almost 70% of the students thought the materials were very clearly organized and constituted an excellent way to study microbiology.

DISCUSSION AND CONCLUSION

Organizing a learning program hierarchically according to Ausubel's and Novak's theory, and using concept maps as a main device, was very well received by students and teachers. It was also a very rewarding experience. The program was found helpful in improving some learning difficulties revealed in matriculation results, as well as in our pretests, as shown in some of the examples we gave.

The topic and concept in which learning difficulties and misconceptions were identified, were specially treated in the development of the program. We tried to reveal possible sources for their occurrence and to treat them accordingly, e.g. students'

belief that microorganisms are harmful, probably originates from everyday experience with microorganisms, and their related medical aspects. This assumption is based mainly on the pretest answers. This subject was carefully treated by planning the text with a "master map." The rather well progress students made on the questions related to these problems, compared with pretests and "comparison" group, might be due to the organization of this topic in the program.

Another source for difficulties we recognized might be the content and organization of textbooks. For example based on the examination of biology textbooks and discussions with teachers, it seems that the essential living conditions are usually not explicitly explained. That might explain the difficulties found in the understanding of the need for water and other life necessities, this is probably the source for lack of understanding of biological principles of food preservation.

The relatively small progress students made in this area, might be a result of too little emphasis put on this topic by teachers. This was reflected in teachers' written reports and in discussions, where they stated that students know already these "simple" topics, and there is no special need to restudy it.

The misconceptions regarding the nature of concepts like "antibody," "antibiotics" or "how is the resistance against antibiotic developed? and its medical importance," were very consistent through matriculation results for several years, as well as in our pretests. Posttest and final maps showed improvement on those topics, although less than we had hoped for.

The confused answers to the question "What is the medical importance of bacteria developing resistance against antibiotic," are similar to results obtained by Brumby (1984), on the problem of "natural selection caused by antibiotics." Brumby also found that students confuse antibiotic with antibody. Answers of the type "bacteria develop antibodies against antibiotic" seem to be of an

intuitive nature and common among many students all over. These kinds of problems are probably hard to change, as shown in our results. Maybe teachers have to get better instructions, to focus their attentions to those problems, which seems to be consistent even after instructions.

Based on our experience we think mapping has a great potential for planning and developing learning programs as was exercised in developing the program in microbiology. It also served as a planning device for some of the teachers who were introduced to maps, and found them helpful.

C.M. also served as one of the means for discovering misconceptions for the researchers, as well as for teachers. As for students work, there are indications, that many of them recognized the value of mapping for knowledge organization, concept understanding and hierarchy, even though not many thought that C.M. is a pleasant occupation. The results of the attitude questionnaire are similar to those of Arnaudin et al (1984). Since we have indications that teachers influence on their students' attitude toward C.M., and their map quality as well. It might be rewarding to train more teachers for a longer period of time, so that more teachers can explore the possibilities of an additional learning device, and learn more about their potential and possible uses, for themselves and their students, as one of the ways to improve meaningful learning.

Table 4: The distribution of students' answers to pretest and posttest questions about general principles.

opened question	type of answer	Pretest			total	Posttest			total
		mappers	no. of maps	compar-ison		mappers	no. of maps	compar-ison	
		n=157	n=23	n=16	n=196	n=233	n=69	n=41	n=343
Importance of micro-organisms in nature	complete	19	0	0	15	53	48	34	50
	partial	45	60	19	44	42	44	49	42
	wrong	36	48	81	41	6	9	17	8
		n=155	n=19	n=23	n=228	n=67	n=34		
Importance of micro-organisms for men	complete	0	0	0	0	46	34	3	39
	partial	37	16	13	31	37	52	85	46
	wrong	63	84	87	69	17	13	13	15
		n=206	n=32	n=31	n=269	n=236	n=64	n=47	n=347
If possible would eliminate micro-organisms	complete	22	9	0	18	65	58	26	59
	partial	46	47	58	48	26	36	49	31
	wrong	3	3	7	3	—	—	2	0.3
		27	41	36	32	9	6	23	10
Biological principles of food preservation									
		n=203	n=48	n=35	n=280	n=236	n=45	n=24	n=305
drying	complete	2	13	0	3	41	22	29	37
	partial	28	13	9	23	38	31	21	36
	wrong	71	36	91	45	21	47	50	27
		n=179	n=51	n=30	n=260	n=21	n=37	n=16	n=263
salting	complete	18	8	7	15	51	62	44	52
	partial	35	24	33	33	30	30	31	30
	wrong	46	67	60	52	19	8	25	18
		n=255	n=57	n=43	n=325	n=226	n=49	n=32	n=307
Freezing	complete	16	10	14	14	31	18	19	28
	partial	11	4	12	10	17	25	12	18
	wrong	73	86	74	76	51	57	69	54
		n=233	n=48	n=33	n=314	n=234	n=52	n=32	n=318
Pasteurizing	complete	13	0	0	10	41	52	28	42
	partial	52	21	33	45	51	33	47	48
	wrong	35	79	67	45	8	15	25	10

*For answers examples see text

Table 5: The distribution of answers to specific concepts, pretest and post-test results

concept	type of answer	Pretest			total	Posttest			total
		mappers	no maps	compar-ison		mappers	no maps	compar-ison	
		n=230	n=54	n=45	n=385	n=217	n=94	n=36	n=347
antibody	complete	8	4	2	7	49	42	6	43
	partial	31	35	31	38	37	38	31	31
	right	37	37	20	35	12	12	50	21
	wrong	24	30	47	26	1	7	14	6
		n=191	n=57	n=44	n=337	n=209	n=91	n=35	n=362
anti-biotics	complete	2	2	7	3	58	41	9	48
	partial	4	0	2	5	12	7	20	11
	right	56	53	46	53	14	32	49	23
	wrong	14	14	5	13	5	6	6	5
	confused with antibody	24	37	41	28	10	15	17	12

*For answers examples see text

Table 6: Distribution of multiple choice answers, pretest and posttest questions

	Pretest			total	Posttest			total
	mappers	no maps	compar- ison		mappers	no maps	compar- ison	
How does antibiotics effect bacteria?								
Choice of answers:	n=248	n=66	n=52	n=366	n=245	n=73	n=55	n=373
1. pH change	7	6	11	7	1	6	6	2
2. disturbing bacteria metabolism	16	4	17	14	72	73	55	70
3. osmotic change	12	10	10	11	17	6	7	13
4. helps antibodies	66	81	62	68	10	16	33	15
Why is resistance to antibiotics a medical problem? Answers:								
	n=254	n=68	n=69	n=371	n=248	n=68	n=55	n=371
1. bacteria develops antibodies	32	31	27	31	12	26	29	17
2. human develops resistance	21	25	25	22	9	9	20	11
3. resistant bacteria can multiply undisturbed	21	16	12	19	62	47	26	54
4. people develop side effects	26	28	37	28	17		26	19

*Encircled are the correct answers

Table 7: Attitudes toward work with maps compared to other learning methods. Distribution of answers (n=218)

Type of activity Activities helps in:	answering questions			studying scientific paper			organizing knowledge in tables			organizing knowledge in C.M.		
	1	2	3	1	2	3	1	2	3	1	2	3
Raising school marks in biology	22	40	38	38	29	24	32	39	30	40	34	26
Understanding concepts learned	21	39	41	29	38	33	25	40	34	29	30	41
Understanding concepts' hierarchy	42	38	42	32	39	29	22	39	40	31	26	43
Understanding how concepts are linked together	39	40	21	32	44	24	15	39	45	19	19	62
Concentrating in main subjects	31	36	33	22	39	39	24	36	40	32	24	33

(1 = disagree, 2 = not certain, 3 = strongly agree)

Table 8: Attitudes toward concept maps, comparison of "mappers" population ("all mappers") to two classrooms where teacher specially favored maps ("teacher mappers") distribution of answers.

Attitudes toward C.M.	All mappers n=263			"teacher mappers" n = 62		
	disagree	not certain	agree strongly	disagree	not certain	agree strongly
1. C.M. is a good way to study biology	22	47	31	16	36	48
2. I intend to study other subject matter with the help of C.M.	45	48	7	42	53	5
3. It's difficult to prepare C.M.	40	47	13	62	28	10
4. Mapping is a waste of time	46	37	17	59	32	10
5. Maps reflect my knowledge in certain subjects	16	45	39	15	40	45
6. C.M. help arrange concepts meaningfully	20	36	44	16	29	55
7. C.M. help discover concepts not understood very well	38	43	19	32	54	14
8. I would like my teachers to prepare C.M. in class	38	43	19	24	54	22
9. It's pleasant to prepare C.M.	53	39	8	43	46	11
10. I like discussing C.M. with friends	69	26	5	59	38	3

Openended questions about C.M. ("all mappers")

a. In what subjects do you think C.M. could be helpful (n=178)	none	Microbiology	Biology	Science	S.Sci.
	11	30	21	11	26
b. C.M. are an heuristic device suitable for knowledge organization (n=95)	disagree	nice but not helpful	sometimes helpful	very helpful	
	11	21	16	55	

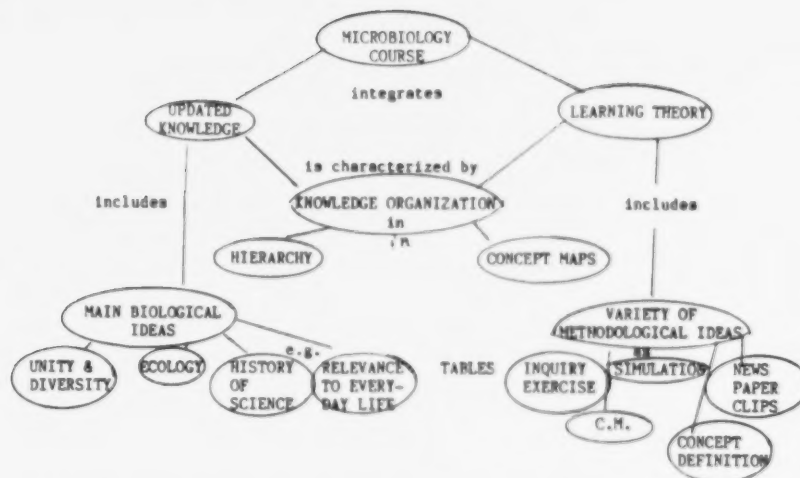


Exhibit 1: A concept map representing the overall idea of the microbiology course we designed.

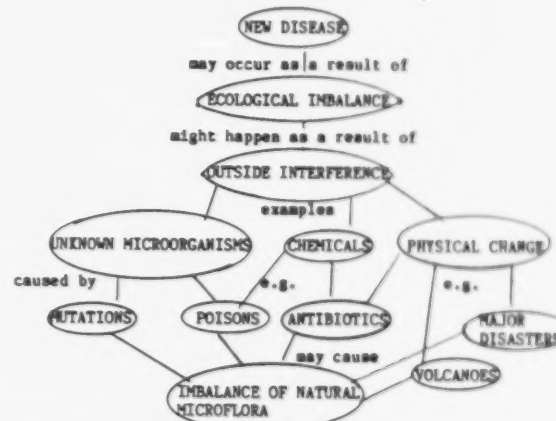


Exhibit 2: C.M. represented in pilot unit, summarizing general ideas of the unit.

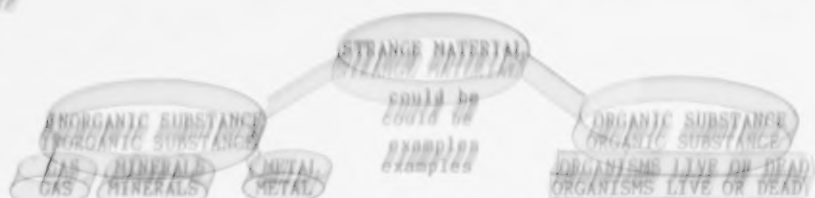


Exhibit 3: C.M. represented in pilot unit showing possible material that might have triggered the new disease described. The map summarizes a single paragraph.

These kinds of maps (Exhibits 2 and 3) were later eliminated from the learning materials.



Exhibit 4: C.M. prepared by 10th grade students, reveals difficulties with Koch's postulates, and lack of proposition between immune reaction and disease prevention. (Broken line indicated misconceptions; notice, no connection is drawn between antibody formation and prevention of disease.)

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Exhibit 5: C.M. prepared by 10th grade students, reveals difficulties with Koch's postulates, and lack of proposition between immune reaction and disease prevention. (Broken line indicated misconceptions; notice, no connection is drawn between antibody formation and prevention of disease.)



Exhibit 6: C.M. prepared by 10th grade students, reveals difficulties with Koch's postulates, and lack of proposition between immune reaction and disease prevention. (Broken line indicated misconceptions; notice, no connection is drawn between antibody formation and prevention of disease.)

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- Caperell, K., Smith, L.L. (1985). Alternative users of networks. Reading Horizons, 25(2), 137-140.
- Cronin, P.J., Dekker, J. and Dunn, J.G. (1982). A procedure for using and evaluating concept maps. Research in Science Education, 12, 17-24.
- Edwards, J., Fraser, K. (1983). Concept maps as reflector of conceptual understanding. Research in Science Education, 13: 19-26.
- Evans, H.R. (1983). Archaeobacteria a new primary kingdom for our classrooms. The American Biology Teacher, 45: 139-143.
- Ferry, G. (1986). Parallel learning in brains and machines. New Scientist, 13 March: 36-38.
- Gurley, L.I. (1982). Use of Gowin's vee and concept mapping strategies to teach students responsibility for learning in high school biological sciences. Ann Arbor, MI: Ph.D. Thesis, University Microfilms.
- Helm, H., Novak, J.D. (1983). Proceedings of the International Seminar Misconceptions in Science and Mathematics. Cornell University, Ithaca, NY.
- Hertig, W.H. Jr. (1976). A new focus in biology education. the American Biology Teacher, 38: 543.
- Honey, J.N., Paxman, H.M. (1986). The importance of taxonomy in biology education at advanced level. Journal of Biological Education, 20:103-111.
- Lehman, J.D., Carter, C., Kahle, J.B. (1985). Concept mapping, vee mapping and achievement: Results of a field study with black high school students. Journal of Research in Science Teaching, 22(7): 663-673.
- Lennox, J.E., Lingenfelter, S.E., Wance, D.L. (1983). Archaeobacterial fuel production: methane from biomass. The American Biology Teacher, 45: 128-138.
- Malone, J. and Dekker, J. (1984). The concept map as an aid to instruction in science and mathematics. School Science and Mathematics, 84(3): 220-231.
- Matthews, G.P., Brook, V.G., Khan-Gandaput, T.H. (1984). Cognitive structure determinations as a tool in science teaching. European Journal of Science Education, 6(2): 169-177.
- Meyer, B.J.F., Freed, R.O. (1984). Effect of discourse type on recall. American Educational Research Journal, 21: 121-143.
- Moreira, M.A. (1978). Experimental college physics course based on Ausubel's learning theory. Science Education, 62(4): 529-545.
- Moreira, M.A., (1979). Assessment of student performance in a psi college course using Ausubel's learning theory as a theoretical framework for content organization. Assessment in Higher Education, 4(2): 119-135.
- Novak, J.D. (1979). Methodological issues in investigating meaningful learning. In: Cognitive Development Research in Science and Mathematics. Proceedings of an International Seminar held at the University of Leeds September (1979). Edited by W.F. Archenhold, R.H. Driver, A. Orton and C. Wood Robinson.
- Novak, J.D. and Staff (1980). Teachers handbook for the learning on how to program. Ithaca, NY: Cornell University.

- Novak, J.D. (1981). The use of concept mapping and Gowin's "V" mapping instructional strategies in junior high school science. Report of the Cornell University "Learning How to Learn" Project: Ithaca, NY.
- Novak, J.D., Symington, D. (1982). concept mapping for curriculum development. V.I.E.R. Bulletin, 48:3-12.
- Novak, J.D., Gowin, B.D., Johansen, G.T. (1983). The use of concept mapping and knowledge Vee mapping with junior high school science students. Science Education, 67:625-645.
- Sobieski, R.J. (1984). Where have all these new microbes come from? The Science Teacher, 51(4): 30-36.
- Spiro, R.J., Taylor, B.M. (1980). On investigating children's transition from narrative to expository discourse: The multidimensional nature of psychological text classification (Tech. Rep. No. 195). University of Illinois: Urbana, Center for the Study of Reading.
- Stewart, J., Van Kirk, J. and Rowell, R. (1979). Concept maps: A tool for use in biology teaching. The American Biology Teacher, 41(3): 171-175.
- Stuart, H.A. (1985). Should concept maps be scored numerically? European Journal of Science Education, 7(1): 73-81.

Misconceptions, Conflict and Discussion in the Teaching
of Graphical Interpretation

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- I Diagnostic Teaching
- II Graphical Interpretation - Aspects of Understanding
- III Graphical Interpretation - Teaching Styles and Their Effects

I DIAGNOSTIC TEACHING

For the past five years we have been working with a group of colleagues (Malcolm Swan, Christine Shiu, Brian Greer, Kathy Pratt, and Barry Onslow) at ways of teaching which take more fully into account how people come to understand some basic mathematical ideas. We have been conducting conversations, interviews and tests with students, looking carefully at their mistakes and using these to help us to understand the ways of thinking that lie behind them. Then we have been devising and trying out teaching ideas and methods aimed at overcoming particular misconceptions, and testing some time afterwards to see how successful we have been. We have come to call this process diagnostic teaching, and we think that it can form a useful addition to the set of teaching methods which we normally use: its key point consists of posing critical problems which promote conflicting interpretations, and lead to resolution through discussion.

Initially we concentrated on a few known problem areas of the curriculum - directed numbers, decimal place-value, choice of operation with decimal numbers, algebra - but subsequently colleagues have been applying the same principles and methods to a variety of other curriculum topics including graphical interpretation, shape and place-value with primary children, probability with sixth-formers. Other outcomes of the work have included some new insights into students' understanding in each of these fields; but also several kinds of classroom-task have emerged as particularly helpful in generating the conflict and discussion needed to promote learning. Making up questions, 'marking homework' (using a real piece of homework or a specially constructed one), filling in tables, and games have all proved useful, and ways of combining group and whole-class discussion have been explored. A full summary report of the research is available from the Shell Centre (Diagnostic Teaching, price £2.50).

II GRAPHICAL INTERPRETATION

The graphical work included in most traditional syllabuses is inappropriate and inadequate, often consisting mainly of plotting the graphs of simple algebraic functions and reading off points of intersection. But by far the greatest use of graphs outside the mathematics classroom is to display the features of some situation or process in a way effective for communication. Examples are graphs of trends in inflation or in house prices, of the rate of decay of radioactivity, of the distribution of expenditure in different categories by a rating authority. What needs to be learnt is how to read and interpret such graphs; this includes not only point-reading and identifying maxima, but also global comparisons and, in particular, awareness of gradients and of the basic types of function, linear, square-law, exponential, and so on. These aspects of understanding were researched by Janvier (1978), and continued development by Malcolm Swan has led to the production of the Shell/JMB teaching and examination module, *The Language of Functions and Graphs*. This section is based on some experimental work during the trial stages of this material; all 8 third-year mathematics sets in a comprehensive school worked with the same unit from this material, with their usual teachers, and took a diagnostic test before and afterwards. Comparisons were made, based on test results and on the observation of the classes, (a) of the way in which the material was used by a high and low ability set and their teachers, and (b) of the contrasting approaches to the material of two different teachers of parallel middle-ability sets. This section will discuss aspects of the students' graphical understanding shown in the diagnostic test; for the two comparative studies, see Brekke (1987).

General Difficulties Observed

- (1) One group of difficulties is the distraction that a graph is a picture of a situation. Overcoming this difficulty is partly dependent on the ability to experience relationships between two variables represented by a cartesian graph.
- (ii) Pupils are usually well acquainted with 'bar charts' and other kinds of frequency graph. These graphs often only consider one continuous variable (frequency), the other axis being used to show even completely independent items. It is then a big step further to realise that graphs can also show the relationship between two variables.

(iii) A third group of difficulties involves choosing between types of variation - linear/curved etc. Even when a student recognises that a function is increasing it is often difficult for her to see what kind of variation is taking place and to relate this to the graph. Should the graph be straight or curved, and, if the latter, should the curve be concave or convex? This is seen here in connection with variables in specific situations eg. speed-time, distance-time, sales.

(iv) A category close to (iii) consists of the difficulties in interpreting gradients and intervals.

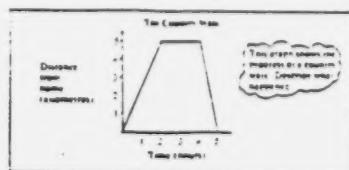
(v) Some of the difficulties the pupils have are not only directly linked to difficulties in making the translation between graphs and situations or verbal descriptions, but are more generally dependent on pupils' ability to give relational responses. Some pupils concentrate on one factor of the relevant data, and exclude the coordination with other factors. We will refer to this problem as fixation. Fixation is not a separate category from those described above: for example, some pupils have problems keeping all relevant factors in working memory when they have to sketch a complex graph from a given situation and tend to concentrate on one or a few. There is also the fixation on only one variable when a relationship between two should have been considered.

Examples from the Test

1) THE GRAPH/PICTURE DISTRACTION

This kind of misconception is extremely common. It accounts for a large proportion of errors on its own, more than half of the pupils are affected by it, and it is also involved with errors that can be traced back to fixation.

The following question is designed to expose this misconception



The picture misconception is illustrated by the following answers.

Samantha:

Describe what happened They all walked up a very steep hill and they when they got to the top it was straight so then when they came down they had to come down a very steep hill again that's what happened.

Some pupils misinterpret the graph as a map of a road.

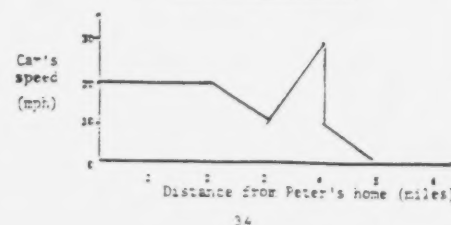
Mandy:

Describe what happened What happened was he or she walk NE for some distance then time one started and rain 5 then they changed direction straight away to go slightly S

In Going to School (see page 37 below) the picture misconception also plays a part. 11% gave an answer like Mandy to part (d).

Mandy:

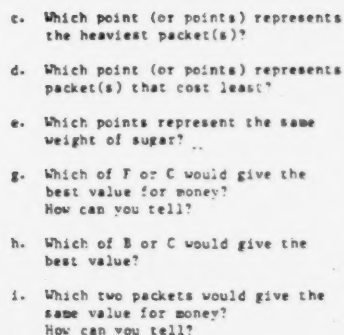
Peter's Journey to School



Mandy is giving a picture of the road from Jane's to Peter's houses, with the highest point corresponding to maximum speed 30 mph. There is no connection between the distance given in the map and the distance on the graph.

1.1) DIFFICULTIES INVOLVING THE RELATIONSHIP BETWEEN TWO VARIABLES

Answers to other questions indicate that the experience these pupils have had with graphs is dominated by block graphs and other pictorial representations of numerical information; 56% gave answers that indicate this. They are capable of plotting points on a cartesian grid and reading off points from a graph where the scale is given. Sugar Prices shows that the problem of looking at one variable at a time is not very difficult.



(2) C. C is less money.

(3) B. ~~Because~~ it is lower in price.

(4) E. they both the same weight and price

(g) 

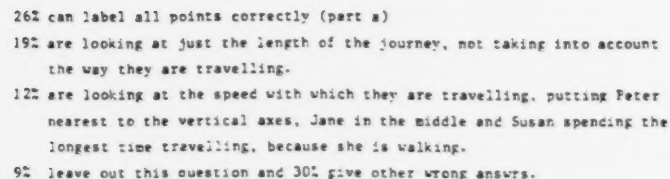
(h) 

(i) 

Not because they have the same difference of height as men do with money.

All answers these are in the
same level as we graph

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(b) Paul Walker and Jason Mizer are ^{born}

(c) because Paul took longer than Carter

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Marianne:

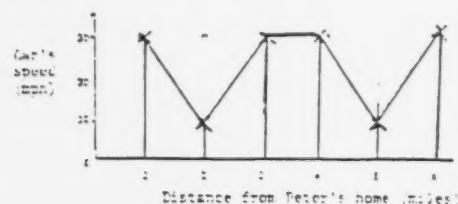
- (b) Waited - Graham Cycled - Paul
 (c) by looking
and seeing that Paul was
further so he cycled - Graham
waited

(116) SHAPE OF THE GRAPH - SIGNIFICANCE OF STRAIGHT LINE VERSUS VARIOUS CURVES

In Going to School and Coach Party the pupils are asked to sketch graphs from given situation, and in the latter question they are also asked to explain the shape of the graph.

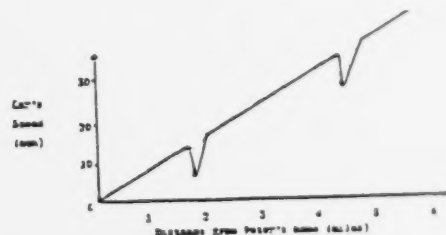
Many pupils sketch the graph as consisting of straight line segments. Those who interpret graphs in a point-wise fashion are especially vulnerable to these kinds of errors: plotting a few points and joining them up by line segments. 28% show such graphs in Going to School.

Jason:



Some pupils only focus on the drop in speed at a bend and ignore the global increase in the car's speed:

Paul:



Similar errors are made in Coach Party.

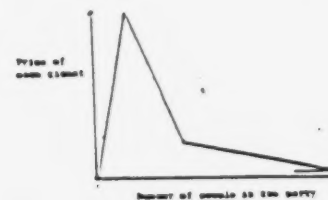
Coach Party

A coach hire firm offers to loan a luxury coach for £120 per day. The organiser of the trip decides to charge every member of the party an equal amount for the ride.

- a) Sketch a graph to show how the price of each ticket will vary with the size of the party.
 b) Write down a full explanation for the shape of your graph.

In (a) 36% sketch graphs that are decreasing, either as various curves (8%), straight line segments (12%), a few points plotted (11%) or histograms (5%); 28% leave out this question. Question (b) is omitted by 35%, the highest amount in the test. 37% give answers that clearly show that they realise that the graph has to be decreasing, but most of them are satisfied with explanations that point out that "the more people that go, the less each has to play". Only 2% gave correct explanations of how the graph is decreasing.

Helen:



(iv) INTERPRETATIONS OF GRADIENTS AND INTERVALS

Pupils find the ideas of gradients and intervals difficult, see Kerslake in Hart (1981), but from what we have found in this test, not harder than other global features of the interpretation graphs.

As far as the graph can be interpreted as a "speed-time" graph a fair number of pupils are familiar with the idea of how to show a changing gradient. But the answers to Coach Party show that it is much more difficult to use the idea of gradient in this case. This may be because the situation is given, or it may be that the graph no longer refers to any ongoing process. Here, each point represents one of a set of possibilities, which is a distinctly more abstract idea.

(v) FIXATION - ATTENTION DRAWN TOWARDS ONE FACTOR OF RELEVANT INFORMATION, EXCLUSION OF OTHER

Some of the errors mentioned in (iii) can be explained by the complexity of the problem. In Going to School several factors have to be considered when one graph is sketched. To get a correct graph showing all the information given, most of the pupils will probably need to do refinements of the graph. A refinement will often occur when a graph is first sketched, and this sketch is compared with the original situation, by interpreting one's sketch graph back into the situation context.

III TEACHING STYLES AND THEIR EFFECTS

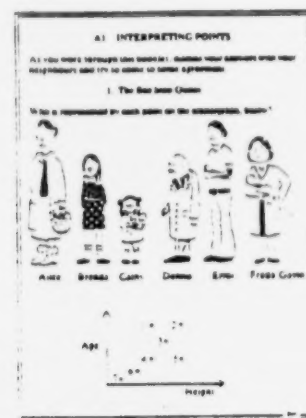
Our last section described the results of a test of graphical understanding. The teaching material in the Shell Centre 'red box', The Language of Functions and Graphs, was developed in response to the aspects of understanding and of conceptual difficulty shown in that test material. In this section we shall describe an experiment in which some of the material was used with all eight third year classes in Haywood Comprehensive School, Nottingham, with observations being made of different approaches in different classes, and their effects.

ASPECTS OF GRAPHICAL UNDERSTANDING

The aspects of difficulty illustrated in the above section fell under five headings. These were: (i) The misconception that a graph is a picture of the situation; (ii) The awareness that a graph displays a relationship between two variables, and is thus more sophisticated than the bar chart which usually displays the quantity of each of a number of separate factors or items; (iii) Recognising the relation between points on the graph, straight line segments and curves and the corresponding kinds of relationship is another aspect of graph-reading skill. The responses to Going to School in the last article showed a number of cases where the speed/time graph of the journey was sketched as a zig-zag of line-segments rather than a smooth curve. (iv) The reading of differences or intervals from the graph also presents difficulties. The graph for Motorway Journey, showing the amount of petrol in a car's tank during a long journey involving two fill-ups, showed difficulties in distinguishing the amount added or used from the final amount in the tank, and the development of reading this difference directly from the grid rather than referring points back to the axes and subtracting. Also involved is (v) the ability to coordinate the information relating to two variables and the two axes. Faulty conclusions often stem from attention to one variable only.

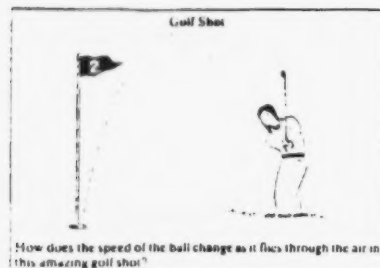
DESIGN OF THE TEACHING MATERIAL

The five lesson booklets of Unit A cover these points, but not in a one-to-one fashion. Booklet A1, Interpreting Points, contains five situations involving coordinating data. Bus Stop Queue (illustration) shows seven people of varying ages and heights, and a graph in which each is represented by a point.



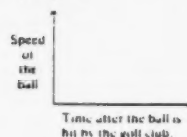
The task is to identify each person with the appropriate point. Intentionally, the scale of height is horizontal, and that of age vertical, so that the natural tendency to assume that a high point corresponds to a tall person has to be resisted in favour of a more careful consideration of which dimension on the graph relates to which variable. So here one aspect of the 'picture' misconception comes into play, but the main problem is one of coordinating the items of information.

Booklet A2 is entitled Are Graphs Just Pictures? It starts with the problem illustrated here, where the graph of the speed of the ball has to be sketched, and this shape is strongly counter-intuitive since it is the reverse of the shape of the path of the ball shown in the picture.



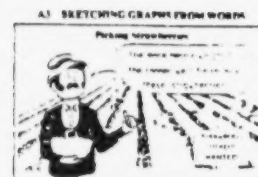
• Discuss this situation with your neighbour, and write down a clear description stating how you both think the speed of the golf ball changes.

• Now sketch a rough graph to illustrate your description.



Roller Coaster is a similar example in which the shape of the track and that of the speed-distance graph conflict. In Which Sport? a speed/time graph looking somewhat like a fishing rod and line is presented, and the task is to decide which of a number of listed sports (fishing, sky diving, pole vaulting, drag racing etc.) it represents. This unit is the one for which the observations of two modes of teaching are presented below.

Booklet A3 is Sketching Graphs from Words. The situations here contain a variety of types of function. In some cases the task is to sketch the graph, in others, sets of situations and of graphs are given, which have to be matched correctly one to one. Examples are Strawberry Picking (time to finish/number of people employed), Balloon (diameter/time as air is slowly released), Race (time/length of race).



• Using axes like the ones below, sketch a graph to describe the situation.

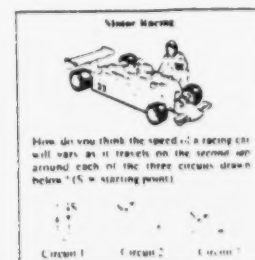


• Compare your graph with those drawn by your neighbour. Try to come to some agreement over a correct version.

• Write down an explanation of how you arrived at your answer. In particular, answer the following three questions:

- should the graph slope upwards or slope downwards? Why?
- should the graph be a straight line? Why?
- should the graph meet the axes? If so, where? If not, why not?

Some of these examples (eg the first and third here) present a higher level of abstraction in that the graph is in no sense a picture of a train of events in time, but a set of possibilities. Each point represents one of all the possible situations. In this set the inverse proportion type of graph also appears, where the graph approaches the axes asymptotically, but does not meet them; this is another point which needs a serious discussion. Booklet A4, Sketching Graphs from Pictures, is essentially a more advanced version of A3. It includes The Racing Car problem, where a given speed-time graph has to be matched with the correct one of a set of possible tracks. (This problem was originally developed by Claude Janvier).

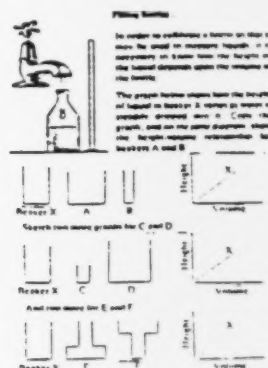


Explain your answer in each case both in words and with a sketch graph. State clearly any assumptions that you make.



• Compare your graphs with those produced by your neighbour. Try to produce three graphs which you all agree are correct.

Booklet A5 concerns gradients and is devoted to the one situation, Filling Bottles. The chief task is to match a set of bottles with a set of graphs, representing the height of water against volume or against time, if we imagine water pouring in at a constant rate. Part of this task is illustrated.



In relation to the five aspects of difficulty mentioned above, Booklets A2 and A3 focus on the Picture misconception, A3 and A4 involve the distinction between straight lines and curved graphs; A1 focuses specifically on coordinating information on two variables. But all involve some degree of resistance to the Picture tendency and some coordination of several items of information. The reading of differences and intervals does not receive specific attention in these units.

METHODS OF TEACHING WITH THE MATERIAL

The materials in the Language of Functions and Graphs are written with the objective of provoking reformulation of children's ideas of graphs. The material focuses on the known errors or misconceptions by beginning with a rich exploratory situation which contains a conceptual obstacle. The questions are deliberately posed in such a way as to allow the errors to come to the surface. This is done by exploring the task in pairs or in small groups, consulting and discussing with each other, and working towards group consensus. Then there is a presentation of the findings to other groups. There could also be a class discussion of the findings, which gives yet another opportunity for remaining errors or misconceptions to come to the surface and be resolved with the participation of the teacher.

The teaching method suggested in the Language of Functions and Graphs is based on research evidence which supports the view that teaching styles which involve deliberate exposure and discussion of common errors with children are more effective than styles which avoid exposing the errors (see Bell et al (1985) Diagnostic Teaching, Swan (1983) Teaching Decimal Place Value - a comparative study of Conflict and Positive Only, and Onslow (1985) Overcoming conceptual obstacles concerning rates - design and implementation of a diagnostic teaching unit).

The five worksheets of section A have been successfully used to initiate discussions of concepts and errors with a variety of classes. Each worksheet starts with a relatively difficult problem to force common misconceptions to the surface. For different classes, existing concepts and misconceptions will be different, and therefore the aims for the discussions will differ too. For the lower ability range some of the teachers expressed a need for some intermediate stages, as the problems were too complex; they felt that the group would cope more easily with a more gradual move from the concrete situation to the more abstract representation of the situation by a graph.

EXPERIMENTAL DESIGN

The materials were used in all eight third year mathematics sets at Haywood School, Nottingham. These were two sets at each of four ability levels. The teachers involved were the normal teachers of these classes. All lessons at the top two levels, and some of the lessons in the other sets were observed and audiotaped. Two lessons were videotaped.

The teachers were given the worksheets and the teaching notes from The Language of Functions and Graphs with no further direction on the teaching method, except for one teacher in Haywood School who was asked to teach with reflective discussions after each exercise. This teacher was also asked to pay attention to the identification of misconceptions, and to discussions concerning the strategies used and outcomes obtained in each lesson.

Two sets of comparative observations were made. One was of the use of the material in two classes of widely differing ability (We hope to describe this later). The other, which is the subject of this article was of the variety of ways in which teachers adapted the material to suit their own teaching styles and of the effect of these differences on pupil's learning. The kinds of style difference will be illustrated by describing typical lessons by different teachers with classes at the same ability level, and using the same material.

Many of the teachers observed have commented on the difference between their usual style of teaching and that suggested in the teaching notes. For many teachers it is difficult to organise discussion so that misconceptions are brought to the surface. In fact, some of the teachers organised their pupils by groups, but then spent their time touring the class "helping" the groups in the usual way, without any particular emphasis on exposing and discussing the misconceptions. This showed that the worksheets and the teaching notes were not enough to establish the new style. We have subsequently attempted to meet this problem by developing support material that thoroughly explains each step and its aim and gives examples from practice, including some videotaped examples of various teachers in action. We also explain something of the theoretical background for the method, and give some examples of comparative studies between this method and more directive teaching.

From previous observations we felt that there should also be a retrospective discussion included in the lessons. The aim is to look back on the work, being conscious of the errors one made and how one worked and why. For this reason we asked one of the teachers in the last teaching experiment to include these activities in his teaching to see if this led to improvements different from those of other groups. Another teacher in the school diverged from the general pattern in a different way. He believed more in rule teaching. He tried to help the pupils in a positive way to understand the results in the worksheets by directive teaching, explaining the errors they had made and the right conclusions. To illustrate the difference in style we will give an example from the teaching of two second level groups working on worksheet A2, Are Graphs Just Pictures? Class IIA had spent one and IIB two lessons on worksheet A1 before doing this. (Sheets illustrated above).

CLASS IIA



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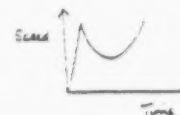
Teacher introduces the worksheet and organises the classroom (5 minutes)

53

Group discussions with groups of different sizes (53 minutes). Every group worked at its own pace with the problems. When a group came up with an agreed answer this was not presented to anyone else, there was no further discussion on the problem. Most of the groups came up with a graph of the speed of the golf ball as:



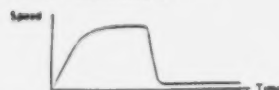
The teacher toured the classroom talking to the different groups, asking pupils to explain their graphs, and when something was wrong he explained why it was wrong and then gave the right explanation. To group G1 which gave graph as above: "This can not be right because the ball then would have had its greatest speed at the top". "The graph must be like this (see diagram below) because it starts off with zero speed, then it picks up speed because it is hit by the club, as it travels up in the air it will slow down, and as it is dropping it will pick up speed because of the gravity". All the while, the teacher was tracing the graph with his finger.



After approximately 20 minutes most of the groups had finished the 'golf ball problem'. The same structure as above continued throughout the lesson.

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Which Sport?
Which sport will produce a graph like this?



Choose the best answer from the following and explain exactly how it fits the graph.

Write down reasons why you reject alternatives



Fishing
Pole Vaulting
100 metre Sprint
Sky Diving
Golf
Archery
Javelin Throwing
High Jumping
High Diving
Snowover
Drag Racing
Water Skiing

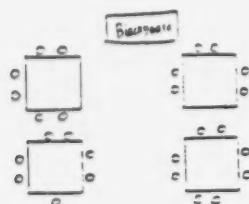
Class teaching Which sport? (5 minutes)

Teacher drew attention to the change of speed in the graph, and asked for answers. The answers given were:

1. Water Skiing
2. High Diving
3. Javelin Throwing
4. Sky Diving

The teacher explained why it can not be either 1, 2, or 3 and why 4 is possible.

CLASS IIB



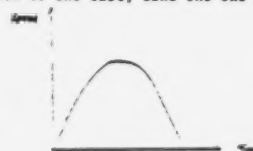
Introduction (4 minutes)

The teacher explained what is happening on the picture, stressing that the speed of the ball varies. He also reminds them of the way of working:

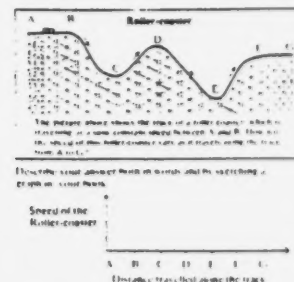
1. Discuss with your neighbour.
2. Try to come to an agreement.
3. Present your answer to the other groups at your table.
4. If answers are not the same try to convince each other.
5. Give final answer from your group to the class.

Work in pairs and groups (20 minutes)

As in Class IIA, more than one half of the pairs have graphs of the same shape as the path of the ball, like the one shown below.



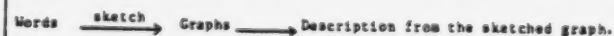
After 20 minutes all the groups were ready to go on to page 2 of the material and to consider the Roller Coaster.



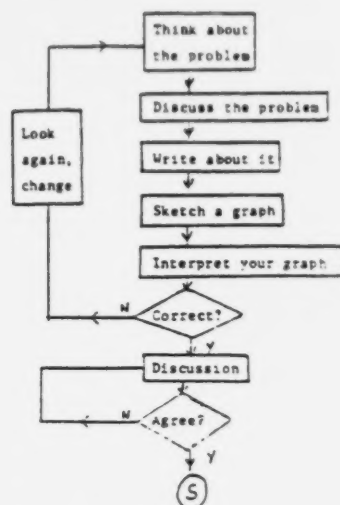
The teacher was touring the classroom, asking questions to provoke discussion.

Class teaching (10 minutes)

The teacher again drew attention to the method in which groups should work. He drew the following diagram on the blackboard:



"See if the two descriptions match - if not we have to change something. You should be able to look at your graph and describe the situation again." A short discussion on the point that the graph shows the relationship between the variables indicated on the two axes then followed (this had been stressed in the two lessons on AI). The following flow chart was drawn on the blackboard:

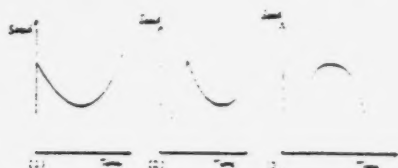


Group discussion (18 minutes)

Groups were using the strategy of interpreting their own graphs and comparing them with the original situation.

Class discussion (12 minutes)

Three graphs were presented on the blackboard.



These graphs were interpreted and (3) was ruled out by the pupils when they saw that the interpretation did not match the given situation. There was some debate concerning (1) and (2) because pupils felt that the ball must start from rest, but they were unclear as to how rapidly it accelerated. A short discussion on this misconception took place at the end of the lesson.

Teacher: "Why do you think people draw the graph like Peter? (3)"

Pupils: "Because they think that a graph is a picture."

Thus there were three main differences in approach between the two classes. In both classes the problem was initially presented to the pupils without teaching. But in IIA the errors made by the pupils were quickly corrected whereas in IIB the pupils, in pairs and groups, came to their own conclusions in discussion, and later presented them to the whole class for further discussion. The teacher did not state the correct answer; and much more serious consideration was given to the errors and the 'graph is picture' misconception which underlay most of them. Secondly, the teacher's main contribution was to emphasise a strategy for working, in particular, that expressed in the flow chart. Finally, the lesson closed with a reflective discussion on what had been learned - the pupils' attention was drawn explicitly to the tendency to regard graphs as pictures and to the need to resist this and to think specifically about the relation between the variable represented on the graph.

PUPILS' ATTAINMENTS - DESIGN OF THE TEST

Five of the eight questions on the test have been illustrated and discussed in the previous section. The eight questions, between them, covered the five aspects of graphical understanding described above, and they asked for responses in four modes. These were (a) Interpreting a given graph, by responding to specific questions (eg Sugar Prices), (b) Interpreting by describing the situation represented (eg Country Walk), (c) Sketching the graph from information about the situations (eg Coach Trip) or diagrammatically (Going to School), and (d) Explaining the reasons for one's answers. There was also a question which asked, 'What is a graph?', and one which referred not to real situations but to 'pure' graphs - it asked about the coordinates of further points on a given line, eg how many points between (2,5) and (3,7), mark 4.6, 10.2 and so on. This last was from the CSMS graphs test and was included to provide a comparison between our classes and their national sample.

Some of the results on the different questions are given below, with a comparison among the whole set of eight classes and each of the two classes where the particular different teaching emphases were being given. They show, in general, quite large gains, and also quite large differences favouring the class where there was special emphasis on critical discussion and on reflection on what had been learned in each lesson.

TEST RESULTS

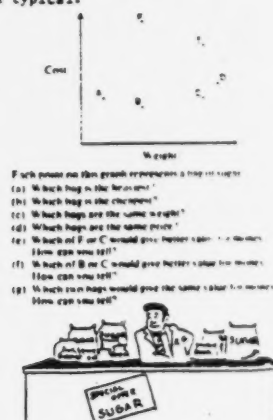
Q1 Write a short description explaining what a graph is

This was a very difficult question to answer adequately. It showed little difference in response pre-post, or between classes IIA, IIB and the whole sample.

Q2 Points and coordinates on a 'puke' straight line graph.

Small improvements. The most difficult questions were on decimal coordinates and number of points between given points or on whole line.

Q3 Bags of Sugar Six points shown, axes cost/weight. Questions about least, greatest, same costs, weights, best value. The mean gains for classes IIA, IIB and the whole sample are shown for each part of the question. We shall not give such detailed results for all questions; these question 3 results are typical.



PRE-POST							
GAINS %	a	b	c	d	e	f	g
All	+19	-4	+24	+18	+22	+21	+9
IIA	+18	-4	+19	+8	+19	+16	0
IIB	+37	+16	+47	+37	+48	+37	+16

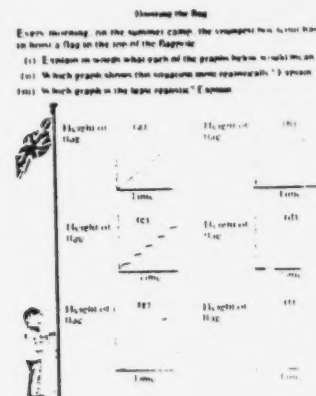
Results for this question show the typical pattern of generally quite large gains, and large differences between IIA and IIB with IIA generally closer to the results for the whole sample.

* Questions 4, 5, 7 and 8 are shown in the previous section

Q4 Country Walk (Description of walk, from distance/time graph).

Results show a similar pattern to those of Q3. Correct responses 25% - 40%, 'picture' interpretation 26% - 20%, speed/time interpretations 21% - 19%.

Q5 Going to School (Interpreting points, sketching graph of journey). Generally large gains but no consistent difference between IIA and IIB.

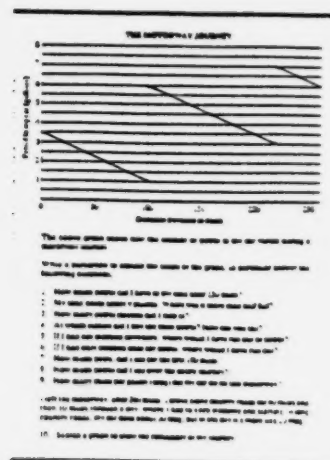


Q6 Hoisting the Flag 6 possible graphs of height/time for hoisting flag up pole, hand over hand; interpretative response and descriptive type questions. Fair gains, small and inconsistent differences between IIA and IIB.

Q7 Coach Trip Sketch graph of cost per person against number in party (inverse proportion); explain your graph.

GAINS	Sketch	Explanation
All	-4	+4
IIA	-4	+4
IIB	+38	+5

A rather good lesson on this is class IIB! But still the quality of the explanations were not much improved. Most responses did not go beyond 'more people, less cost', which would have gained part marks.



*Q8 Motorway, Petrol Graph of petrol in tank; journey with 2 refills. Differences, interpretative, response type questions. Where most petrol bought, when run out if not refilled... 9 part questions, pattern of responses very similar to Q3. Mean gains All +8.5%, IIA +6%, IIB + 18%. Full details of the questions and results are given in Gard Brekke's report.

CONCLUSIONS FROM TEST RESULTS

Going beyond the general observation of substantial gains, and greater improvements in class IIB than in IIA, it is also clear that providing explanations was difficult for the pupils and that on this aspect there was little difference between the two observed classes. The rather open What is a Graph? question also shows little improvement. This would suggest a conclusion that those aspects improved were those where the actual task required by the test question was closely similar to that required in the teaching situations. General descriptions and written explanations of reasons for answers were not much demanded in the teaching, and were not improved. Similarly, the questions on the 'pure' graph involving interpretation and identifying points with decimal coordinates were not treated in the teaching, and were not much improved. On the other hand, the reading and interpretation of differences and intervals, required in the Motorway Journey (petrol) question, was not specifically taught, yet did show large increases in most parts. It would seem that the skills of careful interpretation and attention to the values and changes of the two variables were capable of transfer to difference reading; but that for greater success with explanations, some more specific teaching is needed. For example, it might help if one tried to develop the awareness that one

must try to account for all aspects of the response which is to be explained. Perhaps, better, one might give specific practice in writing explanations and then discussing them critically, possibly by passing them round the group and choosing or constructing a best one, and also by class discussion of some written onto overhead transparencies.

ATTITUDE QUESTIONNAIRE

At the end of the teaching sequence, all pupils were asked to complete a 3-question feedback sheet, as follows:

1. How interesting were the lessons?
very interesting/quite interesting/not very interesting/boring.
2. How hard did you work?
very hard/quite hard/quite lazy/very lazy.
3. How much did you learn?
a great deal/quite a lot/not very much/very little.

When these responses are scored -2, +1, -1, -2 and the mean score calculated for each of the 8 classes we find that on each of the three measures class IIA is the lowest and IIB the highest. For example, for Q1, on interest, the means were (I are the highest and IV the lowest sets):

IA	IB	IIA	IIB	IIIA	IIIB	IVA	IVB
+0.1	+0.9	-0.5	+1.3	+0.2	+0.5	+0.5	+0.6

Thus the general level of response is somewhat towards, but below, the 'quite interesting' level, but IIB gets above this, towards the 'very interesting' level. IIA is getting down towards 'not very interesting' but remains a little higher. The patterns for the other two questions were very similar, eg for Q3, IIA was -0.6 and IIB +1.2.

Thus it is clear that the reflective discussion aspect of the IIB class teaching was generally welcomed and felt to be a good learning situation, whereas the oppositely polarised, more directive teaching IIA was rather less well liked, and thought to be a somewhat less effective learning situation than the average. Of course, we are not comparing disembodied methods but rather these methods with those teachers, for whom these methods were their usual ones, though accentuated for the purpose of the experiment. The teacher of class IIB also reports that the boost to the pupils' recognition of the value of critical peer group discussion and of their skill in using it, which occurred during this period of special emphasis on it, has remained with them and is still visible in their approach two years later.

REFERENCES

- Bell, A.W., et al (1985): Diagnostic Teaching. Shell Centre for Mathematical Education, University of Nottingham.
- Brekke, G., (1987): Graphical Interpretation: A study of pupils' understanding and some teaching comparisons. Shell Centre for Mathematical Education, University of Nottingham.
- Hart, K. (1981): Children's Understanding of Mathematics, 11-16. Murray.
- Janvier, C., (1978): The Interpretation of Complex Cartesian Graphs: Studies and Teaching Experiments. Shell Centre for Mathematical Education, University of Nottingham.
- Onslow, B. (1987): Overcoming Conceptual Obstacles Concerning Rates - design and implementation of a diagnostic teaching unit. Shell Centre for Mathematical Education, University of Nottingham.
- Swan, M. (1983): Teaching Decimal Place Value: A comparative study of Conflict and Positive Only. Shell Centre for Mathematical Education, University of Nottingham.
- The Language of Functions and Graphs (1986): An Examination Module for Secondary Schools. JMB/Shell Centre.

*We apologize for the smallness of type in parts of this article which arose from circumstances of its preparation. We will be glad to send a full size copy on request.

Open-endedness in the Empirical-analytic Mode;
One Conception of Scientific Progress

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* * *

Finley (1983) has argued that the philosophy of Gagne's science processes is based in empiricism and induction and suggests that the commitment to the two philosophical positions has influenced both the scientific knowledge and the manner in which such knowledge is taught. He concludes that because of the inherent problems in empiricism and induction, process based science curricula perpetuate erroneous or simplistic views of science. In Finley's estimation it is necessary that individuals, in science education, restructure their views of the nature of science if we want to avoid misrepresenting, to students, the process aspect of science.

I contend that Finley's argument is accurate as far as he has carried it but through the examination of epistemology it becomes evident a more basic difficulty exists. That difficulty is the world-view of empirical-analytic science. Habermas (1971) critiqued the conceptions of science found in the writings of philosophers and practitioners of science and he concluded that there is no single model of science. Instead, he concluded that there are three forms of scientific inquiry: "empirical-analytic science, historical-hermeneutic science, and critical-social science." Each form of science is governed by individuals' particular interests. These interests are basic to humans and characteristics associated with such interests are connected to specific dimensions of the social world. On this basis scientific knowledge is not a pure, value-free product of an objective methodology; instead it is the

product of an orientation that determines the type of activities to be pursued as well as the form of knowledge that is warranted. The empirical-analytic orientation is the dominant world-view in our society and it is one in which individuals view the world in a technological way. Major values of this orientation are control, certainty, predictability and efficiency. In conjunction with the values there are immutable laws which permit people to identify cause and effect relationships. Individuals who adopt this orientation view themselves as applying a method through which they control events. In effect, they separate individuals from the world and view the world as an object. With the objectification of the world, knowledge is reified and it comes to have meaning other than in the minds of the individuals who constructed it. Associated with this view is a tradition of understanding scientific progress as an accumulation and synthesis of objectified knowledge.

Open-endedness and scientific progress

Biology textbooks, such as Andrews (1980), directly link the nature of science attribute of open-endedness to scientific progress. Such representations of scientific progress reflect the received expansionist view (Rescher, 1984) of progress in which science is seen as inevitably being a continuous, unfinished process. Part of the process is the asking of questions and there is an assumption that the number of possible questions continually expands because the experimental process raises more questions than it resolves. In addition, recent, superior science is seen as

answering all past questions as well as answering present questions. This means scientific progress is associated with knowledge accumulation. Open-endedness is understood in terms of further support for an explanation for a question arising from a current question or answer.

In this paper I maintain that this interpretation of scientific progress is a result of viewing biology from an empirical-analytic orientation and this philosophical stance contributes to students' conceptions of scientific progress. The argument is developed around evidence of teachers' and students' responses to questions posed during semi-structured interviews. The questions focussed on the person's philosophy of science as it relates to biological knowledge and scientific progress. The outcome of the argument is the identification of conceptions of scientific progress and factors that are influential in the formation of students' conceptions.

Data source

A series of informal discussions were conducted in two separate situations. In the first situation three high school biology teachers' lessons on nutrition were recorded. The researcher assumed that the unsettled nature of the topic area gave the teachers opportunities to present biology as a creative endeavour that deals with tentative knowledge. An informal discussion was held with each teacher at the completion of the individual's lessons. Each discussion lasted approximately one hour and the questions

centered around the person's philosophy of science and how it was reflected in the lessons.

The second situation that provided a data source was an introductory biology class in a large adult education institution. The adult students were enrolled in a program to up-grade their academic qualifications in order that they may attend post-secondary institutions. Of the 24 students in the class 9 volunteered to discuss their conceptions of scientific progress with the researcher. The group consisted of 2 males and 7 females, 20 to 37 years of age (mean = 27), who had last attended a science class 2 to 22 years ago (mean = 9.7). The interviews, which varied from 25-65 minutes (mean = 50), were based on questions that reflect the unfinished, expansionary image of scientific progress portrayed in textbooks. For example, questions such as the following were used to elicit students' conceptions of biological progress: Has biology progressed?, In terms of biology, what is scientific progress?, Are there more questions in science today than in past?, Have you heard of science being described as open-ended; if yes, what does that mean to you? What factors in your schooling influenced your view of scientific progress?

All interviews were conducted, by the researcher, on an individual basis. The questions were not worded in an identical manner for the three teachers nor for the nine students because the participants' situations and experiences determined what was relevant. Despite slight

changes in wording of the questions the intent remained constant. Therefore, I contend that the data provide access to teachers' and students' conceptions of scientific progress.

Data analysis

Verbatim transcriptions of the teachers' and students' interviews were prepared. The teachers' data were analyzed according to the subject perspective. That is, the following guiding questions were asked of the information contained in the transcripts:

- (1) What, according to the teacher's definition, constitutes biology as an area of study?,
- (2) What is the rationale for the teacher's knowledge?, and
- (3) How is the teacher's view of a discipline reflected in the lesson material?

The students' data were analyzed for the backing, or justifications, used as foundations for their conceptions of scientific progress.

The analyses were validated on an individual basis by having the teachers and students comment on points they agreed with, disagreed with or did not understand. On the basis of the comments the analyses were rewritten.

From the initial data, portions of the interviews of one teacher and two students' have been selected as

examples of conceptions of scientific progress. In addition, the examples provide insight into factors that influence the students' conceptions. In the presentation below, the discourse is presented in the left-hand column, and comments are presented in the right-hand column. The symbol T signifies the teacher; S-1, S-2 et cetera signify the students; R signifies the researcher.

Episode 1

This episode is from the interview with a teacher who has taught biology for nineteen years. The teacher holds a baccalaureate in biology education and a master's degree in curriculum development in biological sciences. The interview begins with a question based on the manner of presentation in the observed lessons.

Discourse

R: ---

Now, something that you have done in the class, that I noticed, was you made a specific point of teaching the history of biology as you went through that section. Do you normally make a practice of doing that?

T: On this particular topic, for some reason I emphasize it more than other topics. Because the book presents quite a few men in the treatment of the subject and secondly, I guess, I find it an opportunity to see progression more clearly than in some other fields.

Comments

The teacher had presented the autotrophic lessons in a chronological fashion and major experiments were highlighted.

The teacher's explanations presented the experiments as a series of directly related events that built on one another.

During the lessons the teacher did not verbalize, to the

I'm aware of it. But you can see how ideas grow. Starting quite early and how they progress and become more and more complex and more more complicated. --- I think it is an opportunity to point that out. Whether the students get that I don't know, but I definitely was trying to say O.K., the first questions that were asked and the way they were answered was certainly different than the questions questions being asked now and the way they're being answered now. Or the way answers are being sought now.

R: Why do you feel that the history and the philosophy behind those experiments is important to offer the students?

Is there an objective behind your presentation of it?

T: I don't see any value in learning Priestly's name and the date unless I'm using that to communicate progression and how knowledge grows. ---

students, that he was artificially connecting the experiments and that many other experiments would also have been conducted. The idea of progression was implicit in the lessons.

The teacher's treatment of questions was explicit. Specific statements were made concerning the gradual increase in the number of questions as well as the complexity of those questions.

Researcher attempts to establish the reason for the teacher's approach.

Teacher states a basic premise of his/her conception of biology and biological knowledge.

Comments on the teacher's conception

Observations related to the teacher's presentation of biological knowledge led me to the inference that the teacher's conception of biology was strongly influenced by empiricism. This term refers to the notion that reliable inferences are produced by an experimental method based on sense-experience and controlling variables. During a validation discussion the teacher agreed with the inference

and identified the scientific method provided by Arms and Camp (1979, p. 3) as an accurate representation of his/her conception of biology. There is consistency among the teacher's view of biology, understanding of scientific progress and the presentation of a gradual expansion of biological knowledge in the classroom lessons. The consistency is found in an empirical-analytic orientation to biology.

Episode 2

The following two excerpts are from the student interviews. The first excerpt is from the discussion with a student, S-1, whose last science class was a grade 10 biology course, 17 years ago.

R: What is different about biology today compared to 100 or 200 years ago?

Researcher solicits data.

S-1: Here's what I think of it. We started off with the cell theory through Hooke, the cell theory through the cork and now we're splitting the atom. --- And back then you weren't even aware of such things as atoms.

S-1 implies knowledge has increased with the passage of time.

R: So, has biology progressed?

S-1: Oh, definitely. Through the questions and answers.

S-1 demonstrates the received view of scientific progress.

R: In terms of questions asked and answered years ago

S-1: Well they didn't have that many questions to ask years ago, because they didn't know that much about it.

S-1 connects the number of possible questions to knowledge accumulation.

R: So when you say they didn't have many questions, how would you measure progress in biology?

Elaboration requested.

S-1: Just the general knowledge.

S-1 restates the idea of knowledge accumulation.

R: So are you measuring progress in biology by the number of questions we can ask?

S-1: Yes.

S-1 associates scientific progress with the number of questions asked and answered.

R: Are there a certain number of questions we can ask?

S-1: We're constantly learning so, the number of questions constantly increases.

S-1 suggests scientific progress, or knowledge accumulation, is increasing in conjunction with the questions.

The second excerpt is from the discussion with a student, S-2, whose last science class was the equivalent of a grade 9 general science course, 23 years ago. The student's image of scientific progress is very similar to the image reported previously. Important points concerning the foundation of the conception are revealed in the following discourse.

DiscourseComments

R: Can you think of anything in your past where you have picked that up?

Refers to previous comments made by the student that scientific progress is reflected in the increase of questions and answers. Also there is an increase in the complexity of such questions and answers.

S-2: I think it's been from my general interest in the out of doors and taking courses. And also from this current class as well. --- And science generally, you have to have proof or a certain amount of proof before anything is accepted by those scientists out there. So it has to be a progression. I don't see how you can go out on a completely different tangent.

S-2 indicates the concept of scientific progress is based on experiences in certain science classes.

(The discussion continued in this manner with the student outlining a conception of proof that requires controlled experimentation. The student provided an example from the present class and the discussion evolved into a description of how molecular bonding was taught.)

R: When you were taught bonding, how was that taught? Can you describe that?

Request for data.

S-2: Um, [the teacher] did it with pictures, on the board with rings around each one. ---.

S-2 describes the presentation of the Bohr model.

R: So, was it taught to you as fact?

Request for the student's backing.

S-2: Yes, yes. That right.

S-2 indicates the model was presented as information that is certain.

R: Or was it taught as a theory? That there are difficulties with it but this is the best understanding to this point?

Alternatives suggested.

S-2: No. I took it as a straight fact.

S-2 states how the model was understood.

R: When you think of bonding in molecules today, how do you think of it? ---.

S-2: It seemed reasonable to me. Ya, if someone were to ask me that question that is the kind of answer I would give them. ---. I'm here to learn biology and that is what the guy is teaching. And he says this is this and that's what the exam is going to ask you. And if you want to pass the exam you write the correct answers down. Right?

S-2 indicates a conception of bonding that is based on the Bohr model but it is understood to be certain.

S-2 states a justification for the conception and implies that the teacher established it through authority of position.

Comments on the teacher's and students' conceptions

The data from both episodes indicate that the teacher and students understand scientific progress in a traditional expansionist view. The conceptions are characterized by a continual increase in the number of questions that are posed and a corresponding increase in the complexity of the issues dealt with by those questions. The teacher data demonstrates a traditional expansionist view that is consciously taught and it is done for particular reasons. A major reason being, knowledge of the natural world is gained through an empirically based research method and an effective way to understand the natural world is to view knowledge production as cumulative.

The student data illustrates two important points. One, the traditional expansionist view is readily accepted by students. Two, students establish justifications for knowledge according to various factors. An important factor is the teacher's style of presentation. If information is provided as empirically established fact, and presented without conflicting evidence, students seem to accept it unquestioningly. Part of this presentation is the use of the teaching role as an authoritarian position. Students speak of establishing their justifications for knowledge through the teacher's authority as a teacher (Peters, 1967) and not as an authority in science that has provided a reasoned argument. In the case of S-2, the combination of teaching style and the teacher's control over examination results directly influenced the way in which knowledge was conceptualized.

Conclusion

Kuhn (1970) and Lakatos (1970) suggest that the fundamental commitments of a paradigm or research program drive research traditions. That is, basic conceptions determine acceptable problems, the manner in which investigations are conducted, what counts as data, and what is considered to be scientific knowledge. Part of a person's fundamental commitment is the frame of reference the individual uses to view the world. In the data presented, the empirical-analytic orientation is dominant and the individuals view the world from an objective, technically oriented stance. An important element of this

view is the separation of people and the world such that it becomes possible to investigate phenomena in ways consistent with logical empiricism.

As a result of adopting this technical orientation science education has been led to accept a reconstructed view of science that has become known as the "Baconian scientific method." The image of science presented by empirical-analytically oriented teachers is a logical process in which scientific knowledge is established or discovered. In conjunction with the scientific process there is a linear accumulation of facts and concepts. Consequently, scientific progress is interpreted to be a continual expansion of questions and answers.

In bringing this paper to a close, it becomes evident that students' conceptions of science are influenced by broad epistemological questions such as world views and conceptualizations of knowledge. Given the criticism of the traditional conception of scientific progress, along with the empirical-analytic view, there is an implicit suggestion that an alternative view be considered. I propose that science educators consider scientific progress from a frame of reference in which meaning, instead of explanation, is the central issue. This means shifting philosophical perspectives from an empirical-analytic view to a historical-hermeneutic view. Such a view casts people in a

role where individuals give meaning to situations by interpreting events. In such a view a person does not consider knowledge as an object that has direct correspondence to nature; but rather, the person understands knowledge to be a human creation.

References

- Andrews, W.A. (1980). Biological study: An introductory study. Scarborough: Prentice-Hall.
- Finley, F.N. (1983). Science Processes. Journal of Research in Science Teaching, 20, 47-54.
- Habermas, J. (1971). Knowledge and Human Interests. Boston: Beacon Press.
- Lakatos, I. (1970). Falsification and the methodology of scientific research programmes: pp. 91-196 in Lakatos, I. and Musgrave, A. (eds.) Criticism and the growth of knowledge. Cambridge: Cambridge University Press.
- Peters, R. (1967). Authority, Responsibility, and Education. New York: Atherton Press.
- Rescher, N. (1984). The Limits of Science. Berkeley: University of California Press.

A Programmatic Approach to Teaching and Learning About Student Understanding of Science and Natural Resource Concepts Related to Environmental Issues

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The problems facing science educators are numerous and scientific literacy of youth is an important popular concern.^{1,2,3} Over the past several years science education in general has been viewed as if in a crisis state.⁴ One step toward solving these problems is to design science curricula based on real life events, up to date scientific information and students' existing knowledge about their world. Today's environmental problems and issues are front page material and they have the potential of making science real and adding meaning to both teaching and learning. Science and environmental studies can be taught as an integral unit to help students overcome the misconception that science is only for scientists, and the incorporation of environmental issues into the present science curriculum can increase the relevance of science topics studied.

The University of Maine, College of Education, Science and Environmental Education Program has instituted a graduate level course designed to help students learn concepts and skills useful for the development of environmental education curricula and help address critical problems in science education. ESC 525, Planning the Environmental Curriculum,

is a practical hands-on workshop experience in the planning of relevant natural resource-based curricula for elementary, middle and secondary students. Each semester a specific topic is selected and students analyze available primary information and assess public school students' relevant understanding of those concepts. The combined scientific and student knowledge forms the basis for the design of meaningful classroom activities.

Over the past three years ESC 525 has been offered twice and has involved twenty eight university students who focused first on natural resources in the Gulf of Maine (1985) and then Acid Deposition (1987). These topics are of particular interest to people in Maine and Atlantic Canada since both are critical international resource issues. Several students have gone on to design and implement classroom based curriculum based on the results of our studies.

The strategy used in ESC 525 is described in this paper and involves five steps: 1) identification of an appropriate environmental issue, 2) concept analysis of related science and natural resource topics, 3) design and implementation of student interviews at fourth, eighth and eleventh grades, 4) analysis of interviews and 5) report preparation.

RATIONAL FOR METHODOLOGY

NATURE OF PROGRAMATIC RESEARCH EFFORT

Research in science education has traditionally been centered at institutions of higher learning particularly in colleges and departments of education. These programs can be characterized by particular approaches to educational research. Among these it is easy to identify large scale programs which maintain a "critical mass" of faculty and graduate students. This number can be as much as 12 faculty involved exclusively in science education. Another type of program at what might be considered "medium" size state universities may involve from 4 to 6 faculty, and yet another example of 1 to 3 faculty typifies a "small scale" program.

¹Brown, F.K. and Butts, D.P., eds. 1983. *Science teaching: A profession speaks*. Washington D.C.: National Science Teachers Association.

²Opel, J.R. 1982. Education, science and national economic competitiveness. *Science* 217: 1116-1117.

³Press F. 1982. The fate of school science. *Science* 216: 1055.

⁴Yager, R.E., ed. 1980. *Crisis in science education*. Science Education Center Technical Report No. 21. Iowa City: The University of Iowa.

It is these small scale programs (the University of Maine is an example) in which a new type of "programmatic" effort is evolving. Unlike "critical mass" or "medium size" programs, smaller institutions are often limited in funding levels and in full time staff and faculty. In response to these limitations we have focused on small scale, relatively local studies and the integration of a research team approach within the context of our graduate course offerings. The methodology described in this paper is an outgrowth of this evolution.

It is important to note that small scale programs can effectively work within the context of a larger programmatic research effort which can be international in scope. In a recent article in the *American Psychologist*¹ Susan Carey refers to misconception research efforts as "a highly productive cottage industry". In other words small scale programs or research efforts, such as much of the misconception research, may constitute a discrete and valuable unit of effort within a larger programmatic research thrust. The "cottage industry" analogy can be extended and elaborated by considering the changing nature of society and industry.

In the late sixties and early seventies there was a growing ecological conception that large scale agriculture and development programs were actually depleting our resources and contributing to a decline in biological diversity.² This was followed by the popular conception that society was changing from an industrial, large scale, highly centralized, mass production age to a communications age characterized by local small scale opportunities and networks which collectively had the potential to increase our productivity and effectiveness beyond the centralized approaches.³

¹Carey S., 1986, Cognitive Science and Science Education, *American Psychologist*, Vol. 41, no. 10, 1123-1130.

²Leopold, A., 1966, *A Sand County Almanac*, A Sierra Club/Ballentine Book, Oxford University Press Inc.

³Naisbitt, J., 19882, *Megatrends*, Warner Books inc. New York, NY.

If we consider the papers included in the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*¹ (and the schedule of papers presented here) and note the type of research and the institutions which the authors hail from, it is easy to see that there is a trend towards small scale programmatic work in this area. Informally colleagues interested in misconceptions research have referred to a "university without walls." A modern conception may be of a diffuse network throughout the world which may collectively have a synergistic effect on our understanding of particular educational problems. This has great implications for the future direction of research in science education.

In response to the basic necessities of conducting valid and reliable research in a small institution in a predominantly rural environment, and given environmental, social and economic indicators, we have committed ourselves to the redesign and innovation of our teaching, service and research efforts. This paper describes one step in this evolution of ideas and practice which are part of a total redesign of the College of Education at the University of Maine.

NATURE OF KNOWLEDGE

The basic assumption in the development of this program has been that knowledge is an activity in which individuals (or teams of people in this case) participate and construct new knowledge based on previous knowledge. This seems to be a concept which is at the core of science education in general since the word science itself is derived from the French *,sciens* , meaning having knowledge².

The constructivist perspective is a view of science which has been growing in popularity as evidenced by the philosophical

¹ Helm, H. & J. Novak, 1983, *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*, Cornell University, Ithaca, NY.

² Webster's Seventh New Collegiate Dictionary, G.&C. Merriam Company, Springfield, MA.

and theoretical assumptions underlying many of the recent papers presented at national conferences such as the National Association of Research in Science Teaching.¹ This has been a growing trend during the 1980's and is in some ways a reaction to the empirical quantitative studies which have increasingly been dismissed as having little practical value for science educators.

The constructivist perspective in science and particularly in science education research has been an important component of our course work. Graduate students in science education need to be exposed to these ideas not only in the context of science content and teaching but also as an integral guiding paradigm for meaningful research in science education. ESC 525 attempts to integrate these ideas in a practical "hands-on" type of course offering.

NATURE OF THE LEARNER

Learning is the comprehension and acceptance of concepts which are intelligible and rational to the learner. Learning is not simply the acquisition of a set of correct responses anymore than science is simply a collection of laws and principles. Meaningful learning can be considered a process of conceptual change which occurs in two distinct phases, assimilation and accommodation². Assimilation occurs when the learner uses existing concepts to deal with new phenomena; accommodation occurs when the learner has existing concepts which are inadequate to allow him/her to comprehend a new phenomena, and the learner must reorganize his or her existing conceptual framework. Therefore, a critical condition for meaningful

learning is for the teacher to determine what the learner already knows. Of the many variables that influence learning in science, the learner's relevant background knowledge and his or her existing internal conceptual framework are two of the most important.¹²³ Once this information is obtained, teaching strategies may use what the learner knows to add new knowledge to the conceptual framework; existing concepts must be integrated with the new information and incorporated into the framework.

Since the late 1970's many studies have focused on students' conceptions of the world.⁴ These studies have addressed scientific concepts related to heat, the nature of matter, light, living, photosynthesis, the human body and others. Although these studies have led to a greater awareness of the effects of prior knowledge and misconceptions on the learning of specific science concepts, few studies have dealt with the student's knowledge of the multidisciplinary aspect of current science/environmental issues. Our research at the University of Maine is not limited to a particular scientific conception within a particular discipline. It addresses relevant science concepts in relation to real life events and issues, bringing together several natural and social science disciplines. We believe this is a valuable approach since it deals with student knowledge of larger, more inclusive, conceptual frameworks rather than isolated notions.

¹ National Association of Research in Science Teaching, 1986, *59th Annual NARST Conference Abstracts of Presented Papers*, SMEAC Information Center, Ohio State University, Columbus, Ohio.

² Posner, George J., Strike, Kenneth A., Hewson, Peter W., & Gertzog, William A., (1982). Accommodation Of A Scientific Conception: Toward A Theory Of Conceptual Change. *Science Education*. 66(2), 221-227.

¹ Novak, Joseph E., & Gowin, D. Bob, (1984). *Learning How To Learn*. Cambridge University Press, Cambridge, England.

² West, L.H.T., & Fensham, P.F., (1976). Prior Knowledge Or Advance Organizers As Effective Variables In Chemical Learning. *Journal Of Research In Science Teaching*. 13(4). 297-306.

³ Carey, S. 1986. Cognitive science and science education. *Am. Psychologist*. 41(10): 1123-1130.

⁴ Helm, H. & J. Novak, 1983, *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*, Cornell University, Ithaca, NY.

In formulating the approach to our research, we are guided by several theoretical perspectives: (1) before assessing student knowledge in any domain, the major concepts and organizing principles of the knowledge domain must be identified¹; these principles should be broad and inclusive, stressing conceptual relationships and meaning rather than isolated facts, (2) the assessment of student knowledge through interviews provides a more comprehensive picture of student understanding of concepts and conceptual relationships than other more frequently used assessment techniques, such as multiple choice tests,² and (3) the assessment of knowledge in a given domain can provide information useful in the design of curricula and educative materials that address the conceptual problems and misconceptions of students directly, and that introduce new and difficult concepts in ways that will facilitate non-arbitrary (meaningful) linkage of those concepts to existing relevant knowledge in students' cognitive structure.³

The modified clinical interview approach is used in this study to determine the relevant concepts already established in the cognitive structures of the students involved, and to determine if they are inclusive enough to incorporate the more differentiated and detailed science and natural resource concepts related to environmental issues^{4,5,6}. This approach helps guarantee the

¹Champagne, A & L. Klopfer, 1984, Research in Science Education: The Cognitive Perspective in D. Holdzkum and P. B. Lutz (eds) *Research Within Reach: Science Education*, National Institute of Education, Washington, DC.

²Novak, Joseph E., & Gowin, D. Bob, (1984). *Learning How To Learn*. Cambridge University Press, Cambridge, England.

³Ausubel, D.P., J.D. Novak & H. Hanesian. 1978 *Educational Psychology: A Cognitive View*. New York. Holt, Rinehart & Winston.

⁴Ausubel, David P., (1960). The Use Of Advance Organizers In The Learning and Retention Of Meaningful Verbal Material. *Journal Of Educational Psychology*. 51(5). 267-272.

⁵Kahle, Jane Butler, (1978). *A Comparison Of The Effects Of An Advanced Organizer And/Or Behavioral Objectives On The Achievement Of Disadvantaged Biology Students*. National Institute Of Education, Washington, DC 2-14.

availability of relevant anchoring ideas in cognitive structure, and can provide a vehicle for the student to understand the relevance of existing concepts which is a necessary condition for meaningful learning¹.

The rationale for this study is based on the importance of established concepts available within the cognitive framework of a learner. This can make the introduction of potentially logical new concepts meaningful and provide stable anchorage for the new concepts. The more inclusive concepts of a discipline can be the anchoring concepts or subsumer, helping learners identify already existing relevant content in their cognitive structure, and indicating both the relevance of the existing structure and the material to be learned. The principle goal of our work is to bridge the gap between what the learner already knows and what s/he needs to know in order to understand basic ecological issues.

One specific application of this study is in the area of misconceptions and naive theories. Naive systems show remarkable consistency across diverse learners, and are resistant to change by traditional instructional methods. Traditional curricula apparently do not facilitate an appropriate reconciliation of pre-instructional knowledge with the content of instruction.^{2,3} Our work is designed to help overcome the severe limitations imposed when teachers and curricula do not

⁶Pella, Milton O., (1969). Three Levels Of Abstraction Of The Concept Of Equilibrium And Its Use As An Advance Organizer. *Journal Of Research In Science Education*. 6. 11-21.

¹Ausubel, D.P., J.D. Novak & H. Hanesian. 1978. *Educational Psychology: A Cognitive View*. New York. Holt, Rinehart & Winston.

²Helm, H. & J.D. Novak (eds). 1983. *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*, Cornell University, Ithaca, NY.

³Champagne, A.B. & L.E. Klopfer. 1984. Research in science education the cognitive psychology perspective in D. Holdzkun and P.B. Lutz (eds), *Research Within Reach: Science Education*, Washington, DC National Institute of Education

take the students' preexisting knowledge structures into consideration before the presentation of new concepts.

METHODOLOGY

The topics of natural resources in the Gulf of Maine (1985) and Acidic Deposition (1987) were selected as relevant environmental issues in the state of Maine based on a survey of popular magazines and newspapers published in Maine. Relevant primary scientific research publications were identified and conceptually analyzed to compile the content principles related to the topic of study. The content was concept analyzed using group evaluation of concept maps constructed from primary research articles. These were separated into five subsuming concept areas; geologic and geographical concepts, physical and chemical processes, ecology, economics, and political concepts. Concept maps were constructed by each individual on the research team for the five major concept areas¹. The concept maps took their final form after long discussions of conceptual relationships and after a consensus of the entire team was reached (see Figures 1). From the five finalized concept maps, content principles concerning the Gulf of Maine and Acidic Deposition were compiled as a guideline for student interviews (see Tables 1 and 2).

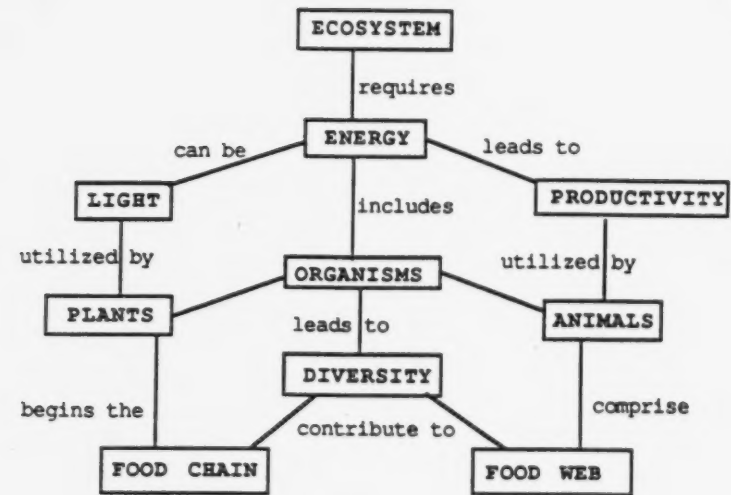


Figure 1. This concept map includes principles 6, 7, and 8 from Table 1 on the Gulf of Maine (1985). It covers those concepts related to ecology.

¹Novak, Joseph E., & Gowin, D. Bob, (1984). *Learning How To Learn*. Cambridge University Press, Cambridge, England.

TABLE 1.
CONTENT PRINCIPLES USED IN THE ANALYSIS OF
THE INTERVIEWS CONCERNING NATURAL
RESOURCES IN THE GULF OF MAINE (1985)

1. The Gulf of Maine is separated from the Atlantic Ocean by Georges Bank and is bordered by the eastern coastlines of the U. S. and Canada.
2. The ocean bottom is continuous with the continent, has slope, gets progressively deeper and is interrupted by bottom features such as channels, banks and shoals.
3. Ocean water in the Gulf of Maine is characterized by low temperatures and salinity, which is primarily the result of fresh water inputs from the continents.
4. Ocean water in the Gulf of Maine is nutrient rich.
5. Water in the Gulf of Maine moves because of wind driven waves and currents, river inputs and tides, which collectively result in upwelling and uniformly mixed waters.
6. Energy flows through this system from sun to plants to animals.
7. Within the system, plants capture light energy and use it to make food.
8. Within the system, plants and animals interact in a complex food chain and web.
9. The Gulf of Maine contains valuable living and nonliving resources that people have exploited over time.
10. Renewable resources in the Gulf of Maine (fish, seals, lobster, algae) have been harvested using a variety of traditional techniques (drags, traps, nets).
11. Nonrenewable resources, such as hydrocarbons and gravel, are being considered for exploitation.
12. The Gulf of Maine is also considered valuable for recreation, research, tourism, and other nonconsumptive uses.
13. The Gulf of Maine has traditionally been utilized as a common resource by many nations, and currently there is a conflict over the future use of these resources.
14. Disputes over resources can be negotiated by concerned parties through mutually agreed upon decision making (negotiation).
15. In order to insure a balanced system, management strategies based on conservation and utilization must be practiced.

INTERVIEWS

In our first study, which focused on the Gulf of Maine (1985), one hundred eighty-seven students (187) from twelve schools (12) were interviewed; sixty-four (64) 4th graders, sixty (60) 8th graders and sixty-three (63) 11th graders. In the second study on Acid Deposition, one hundred and seventy five students from eighteen schools in Maine were interviewed: fifty three 4th graders, fifty three 8th graders, and sixty nine 11th graders.

Schools were selected based upon interviewer proximity and convenience. Where possible, interviewers were assigned to interview a grade level close to the level at which they had teaching experience. Interviewers were University of Maine College of Education graduate students enrolled in ESC 525. Rural and urban areas were both well represented. In each school, students interviewed were selected from a particular class based on the willingness of the teacher and the students to participate. The students were not preselected for their level of achievement in science, and were believed to be representative of a heterogeneous population. Approximately half of the sample were females and half were males.

Although schools were selected primarily on the basis of proximity and the convenience of the interviewers, both urban and rural schools were represented as well as schools in communities representing a range of socio-economic levels. Samples of convenience and the use of volunteers have the potential of introducing sampling biases, but we believe the heterogeneous nature of our final samples kept sample bias to a minimum. This is supported in part, by general agreement between the studies and similar results of the statewide Maine Assessment of Educational Progress in Science, which involves sampling of the entire student population in 4th, 8th and 11th grades¹.

¹Maine Dept. of Education and Cultural Services, 1987, *Summary Report of the Maine Assessment of Educational Progress*, Augusta, Maine.

Interviewers were the same students who had previously analyzed primary research documents and secondary sources. Each member of the research team was assigned to one school system. Interview techniques were standardized during practice sessions during class meetings using both audio and video taping.

Interviews were guided by general lead in focus questions, developed from the previously constructed concept maps.¹ Lead in questions were followed by more specific probing questions based on the concepts maps, to determine the presence or absence of concepts and misconceptions, and the student's overall understanding of the major principles. Standardized interview props were used to sustain the interviewee's interest and to focus attention. Each interview was audio taped and lasted approximately twenty (20) minutes.

DATA ANALYSIS

Each member of the research teams in both studies scored his or her own audiotaped interviews. Prior to the actual scoring, the research team reviewed and scored several sample interviews to help improve interrater scoring consistency. During these class sessions interrater agreement exceeded 75% for all content principles in a random sample of several interviews.

After completion of all the interviews in each study, interviewers scored their taped interviews. For standardization of scoring, the principal investigator provided a form which listed specific concepts organized under each of the 12 major content principles. The following rating system was used to rate student knowledge for each of the 56 concepts:

0 - **Concept not asked** by the interviewer or not covered well enough to be rated.

1 - **No understanding of the concept.** Student either had no knowledge or had only misconceptions of the concept.

2 - **Low partial conception.** Student recognized or understood part of the concept.

3 - **High partial conception.** Student recognized and understood most of the concept.

4 - **Complete understanding.** Student recognized and understood the entire meaning of the concept.

Misconceptions were also identified and tabulated as they occurred. Each interview tape was analyzed and rated with the above scale. The mean interview score for each principle and the grand mean interview score on all content principles were calculated for each grade level. For this purpose, misconceptions were given the same rating as completely missing concepts (0). While some researchers may argue that misconception knowledge interferes with learning and should be scored negatively, others contend that they may provide some useful cognitive structure and should be scored positively. These positions are hard to document explicitly, and it is even more difficult to determine just how positively or negatively a misconception should be scored. Consequently, we assigned a score of zero to student misconceptions to represent an intermediary position on these views. One way analysis of variance and multiple range tests were used to determine whether the mean scores of 4th, 8th and 11th grades were significantly different from one another. Similar analyses were done to determine significant differences between the grand mean scores of each grade level. The unit of analysis was the student since the issues and topics addressed by the content principles are multidisciplinary and not restricted to topics discussed in any one classroom at any given time. Our aim was to determine overall differences between 4th, 8th and 11th graders knowledge of environmentally related science concepts

¹Novak, Joseph E., & Gowin, D. Bob, (1984). *Learning How To Learn*. Cambridge University Press, Cambridge, England.

and issues gained through an array of experiences, both inside and outside the school environment. We were not comparing the effectiveness of individual classrooms at specific times, nor were we comparing school systems, although these factors probably contribute to variability in student knowledge.

INTER-RATER RELIABILITY

In the second of our two studies which focused on the concepts related to acidic deposition, there were 18 cooperating researchers, each of whom conducted interviews with approximately 12 students from one of three grade levels in 15 different public schools in Maine. Each researcher evaluated each of his or her own interviews to rate the student's knowledge relating to acidic precipitation. One obvious concern in a study of this magnitude and complexity, as with all qualitative research, is that of inter-rater reliability, or the degree of consistency with which the researchers rated the knowledge of the students. To help alleviate this concern and to report reliability, each researcher interviewed students from one grade level, and all researchers used the same set of concept maps to evaluate their interviews. As a final check of inter-rater reliability, each rater evaluated a single set of three interviews -- one from each grade selected as being representative of that level of knowledge. The inter-rater reliability was then computed as a function of all researchers rating a single interview from each grade level and as a function of researchers rating a single interview from the grade level which they had interviewed. Intra-rater reliability, or the relative stability of an individual researcher in rating a series of interviews, was not considered to be a problem based on a random sampling of interviewers who had checked their reliability by re-evaluating their interviews to determine their rating consistency.

Inter-rater reliability was calculated for each of the concepts and for the content principles, for each grade level. To calculate the reliability level for each concept, a stroke tally of ratings for all interviewers for each interview was compiled.

The highest agreement in a given concept was divided by 18, the total number of interviewers, to get a percentage. This was used as the inter-rater reliability. Based on all interviewers scoring the, same three interviews, one from 4th grade, 8th, and 11th grade, reliability was rated as the percentage of agreement on each item. The scores were; 4th = 59.3%, 8th = 55%, and 11th = 54.7%.

ANALYSIS

Very few interviews covered all concepts found in each principle, but when analyzed collectively they provided an adequate sample for the entire set. The statistical comparisons between grades were compared on the content principle level, not by comparing individual concept knowledge. Although the knowledge of individual concepts is desirable, it is the students' understanding of the interrelationships among these concepts that is important. Concepts are considered the building blocks of content principles and we believe these principles represent a more valid measure of the students' understanding and knowledge structure.

Means and frequencies were calculated for each content principle. A one-way analysis of variance ($\alpha = 0.05$) was conducted for each principle by grade level and an F-ratio was calculated to determine if the differences were statistically significant. If a significant F-ratio was found a multiple range test was done to determine significance between the grade levels.

RESULTS

The mean scores and standard deviations for our first study concerning the Gulf of Maine (1985) are shown in table 3 and figure 2.. Content principles 1 through 15 are analyzed by grade level. An ANOVA analysis ($\alpha = 0.05$) was performed to compare the mean principle scores among all three grade levels. Duncan's multiple range test was used to determine significant differences between grade levels.

TABLE 2.

CONTENT PRINCIPLES USED IN THE ANALYSIS OF THE INTERVIEWS CONCERNING ACIDIC DEPOSITION

1. Geologic processes include sedimentary and igneous processes which produce, among other sedimentary rocks such as limestone, fossil fuel beds as coal and petroleum, vulcanoes, and intrusive igneous rocks such as granite.
2. Acidic precipitation affects the way various rock types are weathered. Soil produced from sedimentary rocks tend to act as buffers against the effects of acidic precipitation; soils produced from igneous rocks have little buffering capacity, allowing acidic waters to leach essential plant nutrients from the soil and also to liberate metals and other toxins from the soils.
3. The products of combustion of fossil fuels, and to some extent volcanism, contribute sulfuric and nitric oxides and dust to the atmosphere. These elements contribute to the production of acidic precipitation.
4. Chemical pollutants and water combine in the atmosphere as a result of reaction triggered by the sun.
5. Weather patterns and wind currents result from differences in heat in the atmosphere and the earth's rotation and result in the transportation of chemical pollutants.
6. Ecology is the study of aquatic and terrestrial ecosystems including living and nonliving components.
7. Living components include producers, consumers, and decomposers combining to create a food web.
8. The system can be altered by increased acidity affecting growth, reproduction and respiration, and may indirectly cause death.
9. Industry based on consumption of natural resources for the production of materials for profit can lead to acid deposition.
10. Acid deposition affects natural resource utilization in recreation and agriculture.
11. Acid deposition occurs within a political system based on local, regional, and global concerns.
12. Conflicts may arise over acid deposition possibly leading to confrontation, negotiation and/or arbitration resulting in treaties, regulation, and/or legislation to solve conflicts.

TABLE 3.

Mean Score ($\pm$ S.D.) by grade.				ANOVA Summary: Grade level comparisons		
Principle	4th	8th	11th	4th&8th	4th&11th	8th&11th
1	0.8(0.6)	0.9(0.9)	1.1(1.0)	NSD	NSD	NSD
2	1.3(0.6)	1.3(1.0)	1.3(0.6)	NSD	NSD	NSD
3	1.0(0.5)	0.7(0.7)	1.0(0.6)	*	NSD	*
4	0.2(0.4)	0.3(0.6)	0.3(0.6)	NSD	NSD	NSD
5	1.0(0.5)	1.1(0.7)	1.1(0.5)	NSD	NSD	NSD
6	0.1(0.4)	0.9(0.9)	0.9(0.7)	*	*	NSD
7	0.2(0.4)	0.6(1.0)	1.2(0.9)	*	*	*
8	1.3(0.7)	1.4(1.2)	1.6(0.6)	NSD	NSD	NSD
9	0.8(0.5)	0.8(0.6)	1.2(0.5)	NSD	*	*
10	1.4(0.6)	1.6(1.1)	1.7(0.6)	NSD	*	*
11	0.1(0.3)	0.5(0.8)	0.8(0.7)	*	*	*
12	0.9(0.7)	1.0(0.8)	1.4(0.6)	NSD	*	*
13	0.5(0.7)	0.6(0.9)	0.6(0.8)	NSD	NSD	NSD
14	0.8(0.7)	1.0(0.9)	1.5(0.6)	NSD	*	*
15	0.6(0.7)	1.0(0.9)	1.5(0.6)	*	*	*
GM	0.8(0.3)	1.0(0.4)	1.2(0.4)	*	*	*

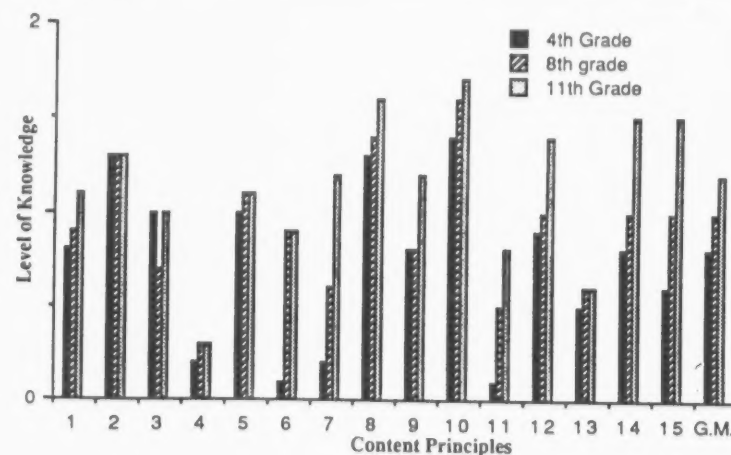


FIGURE 2.

Table 3. and Figure 2. show that the mean interview scores for each principle at each grade level were all relatively low. Table 3. shows the Gulf of Maine (1985) principles for which statistically significant mean score differences were obtained between grade levels. With the exception of principles 6, 7, 11, 14 and 15 these grade level differences were small and do not represent overall differences in the degree of concept differentiation and comprehension of the content principles. Although the grade level grand means were significantly different, the differences were small and indicate relatively minor overall gains in comprehension between 4th and 11th grade. The grand means indicate that, on average, students at each grade level understood only a few basic science and natural resource concepts, and their relationships, concerning the Gulf of Maine.

In our second study concerning Acidic Deposition (1987) statistically significant differences were found on all of the content principles except for principle 10, but only in the comparisons of principles 3, 4, 8 and 11 were these differences found between all three grade levels. On all of the other principles (1, 2, 5, 6, 7, 9, & 12) the differences were only significant between fourth and eleventh grade, and between eight and eleventh grade, but not between fourth and eighth grades. Although Table 4. and Figure 3 indicate that students in our second sample understood more science and natural resource concepts than the students in our previous sample, it is apparent that they still understood only a small fraction of what we consider necessary for a full understanding of these phenomena.

Table 4.

Mean scores and standard deviations for Acidic Deposition (1987) content principles 1-12 by grade level and ANOVA summary. ANOVAs were performed to compare the mean principle scores among all three grade levels. Alpha = 0.05, Tukey HSD post-hoc test. * = Significant differences, NSD = no significant difference.

Content Principle	Mean Score (± S.D.) by grade.			ANOVA Summary: Grade level comparisons		
	4th	8th	11th	4th&8th	4th&11th	8th&11th
1	1.66(.48)	1.61(.62)	1.88(.70)	NSD	NSD	NSD
2	1.50(.46)	1.63(.47)	1.76(.49)	NSD	*	NSD
3	1.36(.31)	1.66(.52)	1.85(.65)	*	*	NSD
4	1.66(.39)	1.87(.50)	2.43(.65)	NSD	*	*
5	1.64(.41)	1.80(.57)	2.42(.80)	NSD	*	*
6	1.84(.57)	1.93(.63)	2.89(.69)	NSD	*	*
7	1.94(.56)	1.87(.60)	2.75(.76)	NSD	*	*
8	1.51(.35)	2.10(.54)	2.29(.73)	*	*	NSD
9	2.10(.69)	2.12(.61)	2.88(.82)	NSD	*	*
10	1.78(.56)	1.86(.69)	2.15(.69)	NSD	*	NSD
11	1.45(.46)	1.80(.53)	2.15(.69)	*	*	*
12	1.45(.46)	1.80(.53)	2.61(.82)	*	*	*
GM	1.61(.30)	1.77(.40)	2.27(.44)	*	*	*

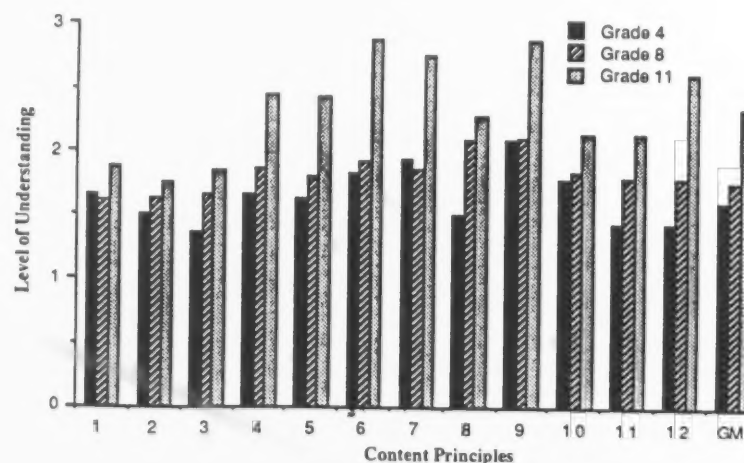


Figure 3.

Table 5. shows generalized student concepts for each content principle related the The Gulf of Maine. The propositional statements represent what we could expect a student to understand about this topic before instruction. As such the list provides a definite place at which to begin instruction and a basic framework on which to build new concepts.

Table 5.

Generalized student correct concepts for each of the content principles related to the Gulf of Maine (1985).

CONTENT PRINCIPLE	CORRECT CONCEPT
1.	The Atlantic ocean is bordered by the eastern coastlines of the US and Canada.
2.	The ocean bottom is continuous with the continents, has a slope, gets progressively deeper and is interrupted by bottom features.
3.	Ocean water is characterized by low temperature, has salinity and rivers and streams run into the ocean
5.	Ocean water mixes and materials move around; waves are wind driven and there are tides caused by the moon's gravity.
6.	Plants need light for something and some animals feed on plants.
7.	Plants need light for something and some animals feed on plants.
8.	Plants and animals interact in food chains and webs.
9.	We have been fishing in the ocean for a long time and there are resources in nature we use.
10.	We fish for fish and shellfish using nets and traps.
11.	There is a possibility there are other resources off our coast.
12.	We use the ocean for swimming, boating and beauty.
13.	Conflicts over resources exist.
14.	Disputes over resources might be solved by people.
15.	Resources can be conserved and utilized if you are careful.

Table 6. similarly shows what science and natural resource concepts we can expect students to understand about acid deposition. These statements form the basic schema which children bring to the classroom related to specific environmental problems, and can form the basis for meaningful teaching and learning.

Table 6.

Generalized student correct conceptions for content principles related to Acidic Deposition (1987)

CONTENT PRINCIPLE	CORRECT CONCEPT
1.	Different types of rocks can be recognized. Fossil fuels include coal and petroleum.
2.	Acidic precipitation affects how rocks are weathered. Water can carry materials out of the soil.
3.	Burning fossil fuels contributes to atmospheric pollution, which contributes to the production of acidic precipitation.
4.	Chemical pollutants and water are in the atmosphere.
5.	Weather and wind patterns, moving west to east, carries pollutants.
6.	Ecology is the study of aquatic and terrestrial ecosystems, including living and non-living things.
7.	Food webs are composed of series of interrelationships.
8.	Systems can gradually be altered by increased acidity caused by acid rain.
9.	Factories produce things for profit, which can lead to acidic precipitation.
10.	Acid rain has a negative effect on certain recreational and agricultural activities.
11.	Within local political systems there are concerns related to acid deposition.
12.	Acid deposition can lead to conflicts with a variety of mechanisms for resolution.

Since the mean score for each content principle at each grade level was low and indicated only partially correct responses, we realized there are crucial concepts in each principle which students were lacking Table 7. summarizes some of the more complex and specific missing concepts related to the Gulf of Maine.

Table 7.
Missing Concepts for each content principle related
to the Gulf of Maine (1985).

Content Principle	Missing Concepts
	1. Gulf of Maine separated from Atlantic by Georges Bank. 2. Channels, banks, shoals; distribution and size of bottom features. 3. Source of salinity, concentration and dissolved gases. 4. Nutrients and their role in ecosystem. 5. Current patterns, upwelling, uniform mixing and distribution of nutrients. 6. Energy flow and conversions in ecosystem. 7. Microscopic algae for primary productivity. Plants use solar energy to make food. 8. Marine species and distribution, complexity of trophic relationships; examples of food chain relationships. 9. Non-living marine resources/exploitation over time. 10. Renewable natural marine resources. 11. Future exploitation of non-renewable natural resources. 12. Oceanographic research. 13. Future exploitation of marine resources, common resources exploited by many nations, knowledge of conflict and utilization process. 14. Mutually agreed upon decision making 15. Balanced system, management, conservation and utilization.

Table 8. list those concept propositions which we found to be missing from the knowledge base of students in our second study related to Acidic Deposition (1987). Both table summarizing missing concepts provide valuable information for teachers who are interested in teaching environmental issues. These are the critical ideas which if learned meaningfully, allow students to make informed decisions about the environment.

TABLE 8.
Missing concepts for each content principle related to
Acidic Deposition (1987)

Content Principle	Missing Concepts
	1. Sedimentary and igneous processes produce, sedimentary rocks such as limestone and intrusive igneous rocks such as granite. 2. Soil produced from sedimentary rocks tend to act as buffers against the effects of acidic precipitation; soils produced from igneous rocks have little buffering capacity, allowing acidic waters to leach essential plant nutrients from the soil and also to liberate metals and other toxins from the soils. 3. sulfuric and nitric oxides contribute to the production of acidic precipitation. 4. Chemical pollutants and water combine in the atmosphere as a result of reaction triggered by the sun. 5. Weather patterns and wind currents result from differences in heat in the atmosphere and the earth's rotation. 7. Living components include producers, consumers, and decomposers. 8. Altered systems affect growth, reproduction and respiration, and may indirectly cause death. 9. Industry is based on consumption of natural resources. 10. Acid deposition affects natural resource utilization. 11. Political systems are based on local, regional, and global concerns. 12. Conflicts lead to confrontation, negotiation and/or arbitration resulting in treaties, regulation, and/or legislation.

The interviews in both studies revealed a number of misconceptions. Most striking among these were:

- coral reefs exist throughout the North Atlantic Ocean
- deep aquatic plants don't need light
- oceans are a limitless resource
- there are no political boundaries in the ocean
- everything in an ecosystem dies if one thing dies
- smoke floats around then disappears or evaporates
- weather comes from the ocean
- acid rain accumulates in the food chain.

Broad misconceptions such as these are apt to influence the meanings students generate for the concepts and conceptual relationships in many of the major content principles. For example, the misconception that coral reefs exist throughout the North Atlantic (held by a number of students across the three grade levels), would undoubtedly influence these students' conceptualizations of the type and diversity of marine life existing in the North Atlantic. The coral reef misconception has very direct implications for how new information can be incorporated into the curriculum. Since the Gulf of Maine characteristically contains cold, nutrient rich, turbid, green water and coral reef formation is impossible under such conditions, this misconception must be addressed before students can fully understand productivity in the Gulf.

Probing during interviews revealed that students gained this misconception primarily by watching documentaries on tropical marine life. It appears they have generalized this information to all oceans.

CONCLUSIONS

Several general conclusions about student knowledge of science and natural resources concepts related to

environmental issues emerged from the two studies:

- (1) students in our studies learn a few basic science and resource concepts in the elementary grades, relevant to current issues,
- (2) there is relatively little further assimilation of new concepts or differentiation of existing concepts as these students progress through the grades, and
- (3) overall, the level of understanding of basic concepts and principles related to ecosystem dynamics, resource utilization and management, and decision-making is low, and it seems that many students do not understand or appreciate the significant role of the environment in our socio-economic past, present and future.

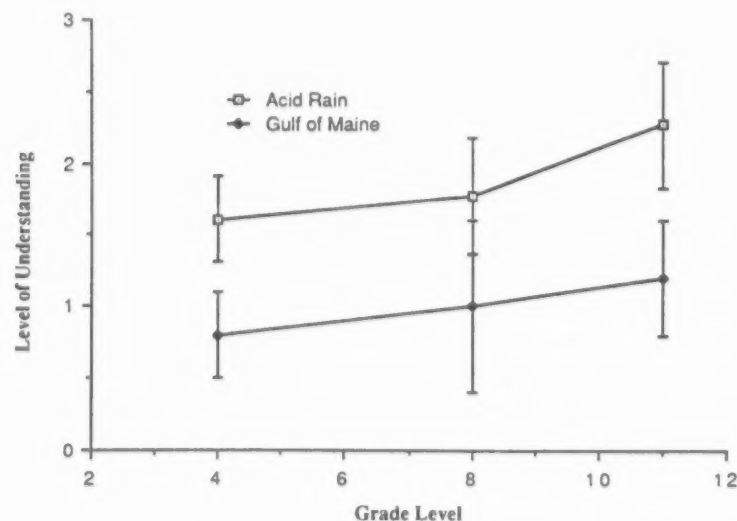


Figure 4.

In Figure 4., the grand means (overall understanding of all content principles) of each study are compared according to grade level and (error bars indicate plus or minus one standard deviation). Students in the acid deposition study understood

slightly more science and natural resource concepts than students in the Gulf of Maine study. It is possible that the more widespread publicity and press coverage given to the issue of acid rain, including presidential involvement, has provided more informal education opportunities and has influenced these relative scores.

In terms of our graduate program there are two general conclusions which we can draw from these two studies. First the nature of our research program has been greatly enhanced by the involvement of graduate students in course work designed to provide practical experiences in research. Second, the constructivist perspective in terms of science content and educational research has led to the design of valuable research methodologies.

Finally our work addresses basic issues in the design of meaningful science and environmental curricula. A viable curriculum should include a set of organized experiences, which will aid students in developing knowledge and awareness concerning the environment. If the curriculum takes into consideration the existing knowledge of students, based upon the 4th, 8th and 11th grade generalized statements encompassing basic science and natural resource content principles and directly addressing student misconceptions, the curriculum can be a more meaningful learning experience for the student.

Our studies can lead to the production of a multidisciplinary curriculum built upon current knowledge and that addresses student misconceptions. Environmental issues involve students with real-life topics. We believe that scientific facts must be accumulated and analyzed in order to make valid value judgements and that science is found in everyday life and is not just the rote memorization of meaningless facts from a textbook. Environmental studies should stress the inter-relationship of all life and the factors which affect life on earth. To preserve this very complex and fragile system we need a general populace knowledgeable in the area of science and natural resources.

Acknowledgements

This kind of research which provides us with such rich data could only be accomplished in the context of a programmatic research effort and with the help of many people. I would like to thank all those teachers, principals and school systems which allowed us to interview their students. In particular, I would like to thank those graduate students who contributed to this effort. These people include: Atheline Nixon, Simon Hassis, Stephen McCoy, Elaine Jones, Peggy Brosnan, Lorraine Nolet, Lori Matthews, George Mayo, George Scott, Dick Derrah, Vicki Nichols, Bob Gaboury, Rob Mosely, Greg Marco, Mark Turski, Andrea Abbott, Roger Brainard, Robert Constable, Cindy Dunham, Sandy Greenwood, Jerry Haggen, Tanis Jason, Andrea Lord, Judy Markowsky, Diane Pelletier, Helmut Koch, Scott Marion, Liz Chipman, Donna Read and Michael Shirley.

The worst evil resulting from the precocious use of speech by young children is that we not only fail to understand the first words they use, we misunderstand them without knowing it, so that while they seem to answer us correctly, they fail to understand us and we them... This lack of attention on our part to the real meaning which words have for children seems to me the cause of their earliest misconceptions, and these misconceptions, even when corrected, colour their whole course of thought for the rest of their life
Emile, J.J. Rousseau, 1760

The term, misconceptions, is in vogue, like the term, 'concept', or 'meaningfulness', its definitions and conceptualizations are lagging far behind its usage. The word, "misconception"¹, is in danger of becoming a sophisticated replacement for the word, "errors". Such a broad use of the word will deny a research tradition a fundamental building block, one which distinguishes a paradigm of research in science and mathematics from its more behaviorist sisters, and as I will argue in this paper, maintaining those distinctions is vital to the continued health of the tradition.

My goals in this paper are three:

- 1) to review three phases in the history of "misconceptions" literature with a focus on the language, the purpose and methods used,
 - 2) to distinguish, within the second phase of development, contrasting trends among the fields of science, mathematics, and computer science in misconceptions research, and
- ¹ I recognize that within the 'misconceptions' tradition, criticisms of the label 'misconceptions' are recurrent, and alternative proposals such as 'student mental models', 'alternative conceptions', 'children's science', 'naïve theories' and 'critical barriers' are often preferred. However, in using the term, I am referring to a tradition of research on misconceptions. Later in the paper, I will discuss the issue of naming this stable but limited belief systems.

3) to propose, within the third phase, a conceptualization of where the research on misconceptions might be heading.

Phase One: The Headwaters

The current trend of work on misconceptions began in the mid70s when researchers in science and mathematics began to document that students were not learning what it is that teachers and researchers thought they were. Researchers, who became increasingly skeptical of paper and pencil achievement tests, sought alternative methods to examine student understanding. People realized that the Piagetian method of the clinical interviewing provided such an alternative method of assessing understanding. In mathematics, this tradition begins with researchers like Erlwanger (1975), Davis (1976) and Ginsburg (1976) who pioneered work which focused on the students' conceptions. In science, Easley (1977) and Hawkins (1974) represent the beginnings of this tradition. Some of the work was concept-specific, such as Peck and Jenks' (1979) work on fractions, other work was problem-specific, such as Clement and Lochhead's work on the translation of algebraic symbols in the students and professors problem (Clement, Lochhead and Monk, 1979; Clement, 1982).

This early work set the tone for much of the later work. It was shown that students' conceptual knowledge was weak and superficial, and that they often relied on memorized procedures, past experiences and informal knowledge. The political ramifications of the studies were widespread, as the researchers documented the resilience and pervasiveness of the misconceptions. Surprise and dismay were felt by audiences as they heard reports of 20-60% correct on alarmingly simple problems. Furthermore, there was an enchantment with the problems, as researchers reported dismal percents, the audience was often lost in calculation and problem solving, introspecting on their own tendencies to answer erroneously, and their care not to fall victim to the enticement of the "trap".

The work was subject-matter specific, yet it was not entirely isolated from the classroom setting. It defined a territory which built from the expertise of the classroom teacher, the identification and anticipation of errors. It also appealed to the mathematician and scientist, since the misconceptions often raised questions about fundamental concepts. It

confirmed what many able teachers already suspected, that despite adequate scores on achievement measures, many students held major misconceptions about fundamental concepts in mathematics and science. At the start, misconceptions were defined empirically as documented failures of large numbers of students to solve problems which appeared to be related to fundamental concepts. Neither their structure nor the structure and choice of problems merited any substantive explanation. *Thus, surprise, pervasiveness, resilience and deviation from the expected answers were the defining characteristics of the early work.*

The early research and the use of the clinical interview led researchers to respect and document students' beliefs. Put simply, researchers learned to *listen to students*. Largely as a result of such earlier psychologists as Piaget (1970, 1973) and Brownell (in Weaver and Kilpatrick, 1972) these researchers sought to describe how the concepts and tasks appeared to the students, rather than comparing their apparent performance against a set of preconceived categories. A value was placed on the process of solving a problem, not just its outcome. As stated by Elwanger (1975):

If children develop their knowledge of mathematics largely through their own activity as they learn mathematics in a particular environment, then evaluation should be an attempt to discover from their point of view just what they have learned and understood (p166)

In order to look at the ideas from the student's point of view, the researchers chose to use flexible interviews and to study individuals or small groups. What they discovered was bluntly stated in an early issue of *Children's Mathematical Behavior*, wherein Davis (1975) wrote

The fact that what was MATHEMATICALLY necessary for the solution of the equation

$$\begin{array}{r} 3 \\ \times \\ \hline \end{array} = \frac{6}{3x+1}$$

differed considerably from what was COGNITIVELY necessary, and the details of how they differed, constitute the main value of the 15-minute interview for us, if not for Henry (p 8-9)

Later in the paper, I will suggest that such a distinction between

"mathematical" and "cognitive" needs refinement, however, it is important to realize that early work such as this contributed to the reexamination and redefinition of what it means to be "mathematical" or "scientific". Philosophers of science were already engaged in work that provided resources for such a reconceptualization.

Davis and Ginsburg has collaborated on early work at Cornell University and within the same issue of *Children's Mathematical Behavior*, a contribution of Ginsburg (1975) provides the introduction of another theme of great significance in misconceptions research. He wrote of the young child as a "intuitive mathematician" (p63), rejecting the "tabula rasa" view of the child, he suggested that "through spontaneous interaction with the environment, he develop various techniques--perceptual skills, patterns of thought, concepts, counting methods--for coping with the quantitative problems." (p64). In his book (recently reprinted), *Children's Arithmetic* (1977) he offers five observations about errors. They are

1. Errors results from organized strategies and rules.
2. The faulty rules underlying errors have sensible origins.
3. Too often children see arithmetic as an activity isolated from their ordinary concerns.
4. Children demonstrate a gap between informal and formal knowledge.
5. Children often possess unsuspected strengths (p. 129)

Clement's work (1982) perhaps was in my opinion the most exemplary of the research on misconceptions in the early phase. In this work, conducted considerably earlier than its publication date, Clement administered to a sample of 150 freshman engineers four word problems, two of which required particular numerical results, two of which were of the "students and professors" type and required a general equation. Their performance on writing equations for particular problems was over ninety percent, on the generalized equation problems, it fell to 63% and 27%, respectively for the two problems.

Clement systematically demonstrated the *compulsion* of the errors by placing a warning with the problems, he comments on their *apparent*

simplicity with the statement, "The data reveal a class of problems which should be trivial for a scientifically literate person, but which are solved incorrectly by large numbers of science oriented students" (p 17). In other work on this same class of problems, he demonstrates the *pervasiveness* of the 'misconception' as similar error patterns are found across different symbol systems: equations, tables, word sentences and pictures.

Clement also demonstrates a characteristic trend in this research when he creates two explanations of the source of the errors: a word-matching strategy and a static comparison strategy. He hypothesizes that these can be used to interpret the statements students make as they solve these problems in think-aloud interviews. He contrasts those approaches to an "operative approach" in which a student "views the equation as an active operation on a variable quantity..." (p.21)

Nowhere in the paper does Clement define explicitly the term 'misconception'. He uses various alternative phrases, "conceptual stumbling block" (p 29), "inconsistent semi-autonomous schemes", "cognitive processes responsible for errors in problem solving" (p 16) whose referent may be "misconceptions" but the relationship is never explicitly offered.

In sum, the early phase of misconceptions research established certain parameters and themes. The dominant perspective was that in learning certain key concepts in the curriculum, students were transforming in an active way what was told to them, that those transformations often led to serious misconceptions. Misconceptions were documented to be surprising, pervasive, resilient and their connections to language and to informal knowledge was proposed.

It should be noted that this research went beyond the simple collection and documentation of errors. Although no epistemological authority was conferred on the students' methods, there was a sense that students were acting sensibly and rationally in their activities, and that these error patterns were appealing and resilient. At that time, they were classified as mathematically or scientifically errant, but psychologically compelling.

Phase Two: The Reservoir

Science Education

Attempts to formalize the concept of "misconception" and to describe its structure, its evolution and its ties to other acts of cognition are characteristic of the second phase in misconceptions research. For example, the operational definition offered by Hawkins, Apelman, Colton & Flexner (1982) to describe a misconception-like phenomena which he calls "conceptual barriers to learning" provides an outstanding illustration.

"First, critical barriers are conceptual obstacles which confine and inhibit scientific understanding. Second, they are critical, and so differ from other conceptual difficulties, because: a) they involve preconceptions, which the learner retrieves from past experiences, that are incompatible with scientific understanding, b) they are widespread among adults as well as children, among the academically able but scientifically naive as well as those less well educated, c) they involve not simply difficulty in acquiring scientific fact but in assimilated conceptual frames for ordering and retrieving important facts, d) they are not narrow in their application but, when once surmounted, provide key to the comprehension of a range of phenomena. To surmount a critical barrier is not merely to overcome one obstacle but to open up new pathways to scientific understanding, e) Another hallmark of the class is that when a distinct breakthrough does occur, there is often strong affect, a true joy in discovery (Section C1)

The definition offers some distinct contributions to the development of an understanding of 'misconceptions'. In the definition, Hawkins' research team required that these 'critical barriers' be pervasive (across age and educational experience), be influenced by preconceptions, have an *internal structure*, like a frame which *serves the purpose of ordering and finding*, and be *significant* so that failing to comprehend it will be an *obstacle*, confining and inhibiting learning. Finally, he has expressed

the affective release and exhilaration which accompanies its breakthrough.

Starting from this characterization of a critical barrier, I will list and comment briefly on a set of themes which are representative of the misconceptions research in science. In reviewing these I will rely on the reviews by Driver and Erickson, (1983), Driver and Easley (1978), Gilbert and Watts (1983), the Proceedings of the Misconceptions Conference at Cornell (Helm and Novak, 1983), and the book Cognitive Structure and Conceptual Change, (West and Pines, 1985). In subsequent sections, I will discuss the perspectives on misconceptions in mathematics, computer programming and statistics.

Preconceptions Researchers in science were often motivated to examine students' conceptions because it was believed that an understanding of a student's prior knowledge determined the appropriate starting point for instruction (Ausubel, 1968, Novak, 1977, Bruner, 1960). As Hawkins et al. (1982) wrote

In contrast with studies which have the aim of "paying attention to what students don't know" Our purpose is always, at least in principle, to find out conjecturally, and more firmly where possible, what students do know, and then how this knowledge can be raised by them to the level of consciousness--retrieved for their own use in further learning. p C-3

The focus on preconceptions represented a basic rejection of a *tabula rasa* approach to learning. The assumption made was that students connect new ideas to existing ideas, and that the existing knowledge thus serves as both a filter and a catalyst to the acquisition of new ideas. To understand what students will learn, one must first determine what beliefs they currently hold.

Conceptual Structure A second theme stresses the structure of relationships among concepts. As described by Pines (1985) the meaning of cognitive structure is.

"Cognitive means "of the mind, having the power to know, recognize and

conceive, concerning personally acquired knowledge," so cognitive structure concerns the individual's ideas, meanings, concepts, cognitions and so on. *Structure* refers to the form, the arrangement of elements or parts of anything, the manner or organization, the emphasis here is not on the elements, although they are important to a structure, but on the way those elements are bound together." p. 101

The rationale for attending to this dimension varies from researcher to researcher. For some, methods of creating conceptual maps, semantic networks etc. are important to provide a more holistic and relational perspective on concepts (Novak, 1985, Pines, 1985). Others emphasize the need to not only understand what is known, but to examine how it is organized (West, Fensham and Garrod, 1985). Still others emphasize on instructional validity for the methods, finding them useful tools to promote consideration of alternative organizations and to reveal misconceptions (Champagne, Gunstone, Klopfer (1985).

The question of how knowledge is organized has evolved both from the Piagetian tradition of examining basic organizing structures such as space, time, object permanence etc., and from the information processing communities with their concern for the limitations of memory. They argued that the sheer quantity of "information" places a demand on humans to organize knowledge to manage, store and retrieve it.

The confluence of these two traditions, Piagetian and information processing, yield a somewhat confused language describing this work. Information processing theorists often imply that we receive "information" from external sources and to comprehend it, we impose our own structures of knowledge organization. Thus, we transform the information to fit within our existing structures. Within such a framework, misconceptions result from the inaccuracies between the structures we create and the external world.

In contrast, when the more Piagetian side of the tradition dominates, one finds that there is less need to speak as though the world sends out "signals" and the concern is for how one negotiates one's own private understandings with what one takes to be the meaning in public utterances by others.

The following two quotes with the span of a few pages illustrates the dubious combinations of language which compete within this tradition of research. West et al.(1985) wrote:

- 1) "When we receive input through our senses, we have to infer a great deal from the input....[an example is given] In fact, the listener needs to infer a great deal and this ability to infer depends upon information stored in the listener's storage memory." (p.34)
- 2) The meaning of a concept for any person is part of his or her private understanding. Yet different people use the same concept labels. Hence public knowledge propositions that contain concept labels may seem to be precise... while the meaning that an individual infers from that proposition depends upon the individual's private understanding of the concepts.(p38)

Early work on cognitive structure tended to be open to the criticism of implying desirable uniformity and completion in representing particular concepts. However, in more current writings, the researchers sensitivity to variations in meaning, from child to child, from context to context is often explicitly mentioned. For example, White (1985) proposed nine dimensions of cognitive structure (extent, precision, internal consistency, accord with reality or generally accepted truth, variety of types of element, variety of topics, shape, ratio of internal to external dimensions, availability) which explained some of the variation Pine expressed simply as "these bundles of meaningful relations we call concepts are, on the one hand, capable of change, and, on the other hand, can never be acquired in any finalistic fashion. Any new relations will affect, to some extent, the total framework of relations" (p110)

For Pines (1985), this allows an definition of a misconceptions within conceptual structures as viewed across time and circumstance. He wrote: "certain conceptual relations that are acquired may be inappropriate within a certain context. We term such relations as "misconceptions". A misconception does not exist independently, but is contingent upon a certain existing conceptual framework. As conceptual frameworks change, what was deemed a misconception may no longer be a misconception, conversely, what is a central conceptual relationship in one framework may be a profound misconception within another framework. The history of science is replete with such examples" (p110)

Hawkins et al. (1982) poses a particularly salient concern, posed in the form of an apparent paradox: suggests that in science as contrasted to common sense knowledge "to understand any one concept, a node in the network logically connected to other nodes, it is necessary to understand many others as well. This logical tightness of scientific ideas, their mutual interdependence, suggests immediately a paradox, they cannot be learned, not in isolation from each other, not all at once, hence not at all. Such a paradoxical conclusion only states, in extreme form, the origin of many of the student difficulties" (C16)

In summary, investigations of cognitive structure led researchers to look at the interrelationships among concepts and to examine the ways of structuring, ordering and fitting together concepts. In most of this work, researchers are careful to distinguish between the meanings students have for concepts and their verbal utterances. The concept map or semantic network is proposed as another source of evidence by which researchers can consider what it is that students believe.

Conceptual Change An alternative but complementary position to the examination of cognitive structure is a focus on under what conditions students will choose to modify, reject or extend their conceptions. Researchers in this tradition, often building from the work of Toulmin on the evolution of conceptual systems, argue that concepts are similar to theories and paradigms; the preconceptions will act as a filter for new concepts, and the new concepts must not only be shown to explain or predict the phenomenon, but they must be regarded as providing an acceptable solution within the current framework (Strike and Posner, 1985, Confrey, 1980, Johansson, Marton and Svensson, 1985)

Formal vs. Informal Knowledge The importance of examining not only what is taught in schools and how it is taught can be demonstrated by research which involves informal learning contexts. Ginsburg (1977) wrote specifically of the differences in Children's Arithmetic,

One of the most significant difficulties in children's arithmetic is the gap between informal and formal knowledge. The phenomenon is widespread many children

have trouble with written work but can cope with the same kind of problem in an informal manner (p180)

He reminds us in that piece of the importance of reducing the gap between formal knowledge, "seen as a meaningless game", and informal arithmetic which "has already proved of some utility" (p181)

Champagne et al. (1985) explicitly discuss this gap, specifying a potential source of imprecision in students' interpretation of propositions. These include the presence in informal meanings for technical terms, errors in determining the scale of measurement (either as inappropriately large or small) and as attempts to formulate general rules from their experience with concepts such as motion.

The terms, informal/ formal, need to be analyzed into their components and/or possible referents. To date, the following interpretations of the distinctions seem plausible, and often their use does not distinguish among them.

1 Formal refers to that which is taught in an organized, structured educational institution where certain constraints and conditions operate that differ from outside life, informal is that which is not taught in such an institution

2 Formal refers to a system of interrelated definitions and proofs, experiments and arguments, informal refers to more tentative intuitive conjectures.

3 Formal refers to written methods, informal refers to mental strategies.

4 Formal refers to the abstraction of an procedure from its context, where the procedure is specified and justified independently, informal refers to routines which are carried out mechanically, by habit or tradition, to complete an activity required on a daily basis.

5 Formal refers to knowledge one "accepts" as legitimate because it has been demonstrated by experts, informal refers to knowledge one has generated/learned through one's personal actions.

The appeal of the formal/informal distinction in researching students' conceptions is great, it captures an expression frequently uttered by students where they draw a distinction between what is required/expected in school and what is required/expected in daily life

apart from school. However, if one takes the first definition, then any distinction attributed to the formal and informal cannot be altered by institutionalized schooling. This is a conclusion most researchers would be reluctant to draw.

Sense data vs. theory. Science educators are particularly interested in how students relate their sensorial experiences to their formal theories. Often researchers will document the isolation between these forms of knowledge. In other studies, it will be suggested that a misconception results from the lack of isomorphism between theoretical perspective and sensory inputs which originate in the real world.

For example, Driver and Erickson (1983) began their article with a quote from Einstein and Infeld:

Science is not a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions. (Einstein and Infeld, 1938)

A fundamental distinction can be made in science or in any field between two general kinds of activities. On the one hand there is the cataloguing of sense impressions, the experience of the phenomena, on the other, there are our attempts as humans to impose some regularity on experience by creating our models or theoretical entities (p37)

As a result of the assumption of this dichotomy, the authors propose the following definition of a "conceptual framework": "By the construct, 'conceptual framework', we shall mean the mental organization imposed by the individual on sensory inputs as indicated by regularities in an individual's responses to a particular problem setting." (p39)

This passage captures one of the most interesting issues within the 'misconceptions' tradition in science: the relationship between ontological claims (claims about reality) and epistemological claims (claims about knowledge). In the passage, the term 'sense impressions' is used first in the Einstein quote and then by the authors. In their definition, they shift to the use of "sensory inputs". Inputs, a

mechanical, computer-based metaphor, often connotes that an external world imposes certain signals on individuals, these are chaotic, and can only be interpretable by the individual through the means of mental organization. Thus, it appears that the authors differentiate sensory inputs as originating externally and mental organization's as personally constructed

If this is a correct characterization, then the authors might conclude that somehow one can assess the accuracy of their mental organizations(internal) in relation to these sensory inputs (external). The assertion that one can assess the accuracy of an internal representation in relation to an external stimulus has been criticized since the time of the skeptics, for any such assessment would necessarily be another internal act of comparison, and fail to overcome the internal/external gap. (von Glasersfeld, 1984) Another more obvious example of such a distinction was stated by Fischer, Lipson and Idar (1983) wherein they write, "We are more or less constantly engaged in assessing the 'goodness of fit' between our mental models and the world around us "(p. 1)

The passage from Erickson and Driver is ambiguous, and would also allow an alternative interpretation, wherein the relationship of "sensory impressions" and "conceptual frameworks" would both be firmly placed within the individual (albeit influenced by social and cultural forces). Hence, impressions are not regarded as external signals, but internal experiences of them. Then the relationships, one wishes to examine are the interactions and relationships between perceptions (organized frameworks of sensations) and other conceptual tools, use of language, symbols and theories. Thus, the issue of ontology, what is reality, is minimized and the relationship among systems of knowledge (of which sensory impressions is simply one of many), is emphasized. Pines (1985) seems to take this position wherein he wrote

Sensation--the raw data from the sense organs--on its own, without perceptual organization, is devoid of meaning. Organized sensation--namely, perception--enables the awareness and mental recording of objects and events. In human beings, such perception is facilitated by language--words or sentences, and thus experience is conceptually and propositionally punctuated into meaningful

distinctions, relations, and complexes of such relations that transform "raw sensation" into perception. (p103)

If one takes the position that knowledge consists of a coordination of internal representations, rather than as a more and more accurate portrayal of "the way things really are", then one is left with one further issue in the definition offered by Driver and Easley. In it, they refer to conceptual frameworks as mental organization ... as indicated by regularities in an individual's responses to a particular problem setting. What is left unanswered is the question "whose perception of regularities they are referring to?" If the answer is an observer's perception of regularities, then a conceptual framework is not necessarily one's own ways of organizing experience, but another's model of one's own. If it refers to one's own framework, then one is left wondering if conceptual frameworks cannot be invisible to the person operating within it. How one answers the question of who the observer is perhaps not as important as the recognition that in such a statement "regularities in responses" is a hidden observer, and this individual needs identification.

Nonetheless, in science, it is clear that one must give careful attention to the role of "sense impressions". Students often consider sensory impressions as non-controversial, given, objective, dependable and the bedrock on which theories are inductively inferred. The phrase "to make sense of it" is evidence of the security provided to us by translating more abstract phenomena into sensory forms. The "chicken and the egg" relationship between conceptual frameworks and the evidence selected and recorded is a serious issue which through this research it becomes evident must be included in our science curricula.

Language The role of language in the construction and maintenance of misconceptions has received considerable attention in misconceptions research in science. Some researchers have focused specifically on the defining and labelling in relation to the structuring of the discipline. In this case, the naming of a significant set of relationships is indicative of its value within the discipline. Pines described the important function of language writing, "A word is like a conceptual handle, enabling one to hold on to the concept and manipulate it "(p.108)

Other work has been devoted to describing the relationships between the use of scientific terms in daily use, such as force, energy, heat and the precise definitions of these terms within the discipline. This relationship was expressed by Solomon (1983) in the following excerpt:

Meanings which are in daily use cannot be obliterated by science lessons, however convincingly presented. Even when the concepts and theories of science have been learned, the older meanings, and loose explications of the life-world, will still linger on. This implies that our students will acquire, through their instruction in science, a second domain of knowledge which is radically different from the first but coexistent with it. Under these circumstances we shall want to know if they are aware of these two competing sets of meanings and, more importantly, how they decide which one to use during problem-solving exercises (p129)

Within this tradition, it is frequently emphasized that the role of language in the construction of understanding extends beyond labelling and communication of propositional knowledge into the social construction of knowledge (Vygotsky, 1976; Skemp, 1971). Described by Wittgenstein as "language games", there is an examination of the larger cultural and social context in which scientific meanings are established (Confrey, 1981; Head and Sutton, 1985).

Sutton (1980) distinguished denotative meanings in science (rigorous definitions) from connotative meanings in everyday experience (a framework of associations and implications). He suggested that science often proceeds by redefining and making precise everyday terms and that scientific terms are also incorporated into a culture through metaphoric extensions on their meanings. Hewson (1985) provided an example of such cultural-scientific mingling in her study of the conceptions of heat of the Sotho group.

Analogy. More recently, researchers in science education have concentrated not only on students' formal ways of tackling difficult problems, but on their use of powerful analogies and models in their attempts to understand scientific conceptual systems (Gentner, 1980;

Rumelhart and Norton, 1980). For example, Clement (1977) explored the analogical relations which doctoral students and professors in technical fields invoked in trying to solve a problem concerning the stretch of a spring. He found that "spontaneous analogies have been observed to play a significant role in the solutions of a number of scientifically trained subjects" (p.1). In addition to documenting the use of analogy, he also explored the processes of generating and extending analogies.

Historical Perspectives. Often researchers in this tradition have studied the historical development of a concept as a rich source for 1) describing some of the potential misconceptions, 2) for demonstrating at least one developmental sequence which leads to the current concepts, and 3) as a source for a variety of problems which provoke consideration of alternative frameworks (Clement, 1983; Lybeck, Stromdahl and Tullberg 1985; Lybeck, 1985; Marton, 1978).

Research on the history of the concept under consideration provides one access to the milieu that often assisted the person(s) in the development of the concept. For example, Confrey (1980) examined the history of calculus and suggested seven different conceptions of number which were held. She documented that according to Boyer, it was the combination of the outstanding problem in the sciences to describe growth and change, the reimportation of algebra from the Mideast and the awkwardness of the theory of ratios which created a setting in which the fundamental concepts of calculus were developed. By examining the history, it became apparent that most students were being introduced to calculus without an understanding that the application of discrete methods to continuous quantities led to disturbing paradoxes. Without this, the students were baffled and resistant to the complexities of limits.

Epistemology. Three levels of epistemological questions have been debated predominantly among these researchers: 1) the epistemological underpinnings of the subject area, 2) the epistemological basis which guides students as they learn science, and 3) the epistemological basis for the conduct of such research.

1) This research is characterized by a rejection of an

empiricist/positivist traditions in which science is conceived of as inductive generalizations on observations. Building from current work in the philosophy of science, (Lakatos, 1970, 1976 Toulmin, 1972), science is characterized as theory-laden from its observations to its theories and its progress is explained in terms of meta-level considerations such as parsimony, elegance, explanatory power, and increasing acceptance by scientists. It is emphasized that the development of scientific ideas will not necessarily parallel the proof. It suggests that educationally the development of ideas may be a more fertile grounds for providing educational researchers insight into learning. (See Strike and Posner, 1985, for an excellent discussion of empiricist commitments.) Much of this work has been the basis for the development of constructivist theories of knowledge in science, and such a reexamination of their own conceptions of science and mathematics must proceed any examination of student conceptions.

2) The implications of "the child as scientist" which result from such a reconceptualization have been highly endorsed with the community (Osborne and Freyberg, 1985). Building from the work of the constructivist, Kelly, Gilbert, Watts and Osborne have promoted the view that the way needs to be investigated is "children's science" as opposed to "adult science". The emphasis here is on the hypothesis that a child may not be "seeing" the same set of events as a teacher, researcher or expert. It suggests that many times, a child's response is labelled erroneous too quickly and that if one were to imagine how the child is making sense of the situation, then one would find the errors to be reasoned and supportable.

In more recent work, researchers have not only documented that students are acting reasonably, but they have begun to describe the basis of their epistemological beliefs. In mathematics, Confrey (1980) argued that students see mathematics as external, unchanging and non-controversial. Schoenfeld (1985) suggested that students are 'naïve empiricists' and that their formal procedures are often not enacted in problem solving circumstances which require discovery rather than proof. DiCessa (1983, 1985) hypothesized the existence of phenomenological primitives which compete in problematic situations and create a significant fragmentation in what students know.

In an article, "Constructivist Goggles: Implications for Teaching and Learning" (1985), Pope outlines the implications of this work for teaching and learning. Many of the ideas are compatible with a paper by Confrey, (1983) in which the implications of constructivism for the Schwab's four commonplaces are discussed. Both of these articles argue that the implications of giving students leeway to possess individually valid intellectual spaces means that classrooms will be modified in terms of conduct and evaluation.

Teaching students to consider these epistemological issues has been approached directly through such techniques as the application of Gowin's Vee (Gowin, 1983), as science educators struggle with the question of how to overcome the oversimplification of the "scientific method." In his work, he demonstrates the viability of using the construction of a map of an event onto two components (hence the vee), conceptual and methodological. Together with the conceptual maps of Novak, these tools provide some alternatives to the dominant modes of evaluation of learning that exist presently.

3) The epistemological questions underlying the conduct of such studies has evolved from an emphasis on striving for normative portrayals to a focus on idiographic studies (Gilbert and Watts, 1983, Driver and Easley, 1978). The case study developed through the use of the flexible interview has dominated the research in this area. As written by Driver and Easley (1978), an ideographic vs. a nomothetic approach are those, "in which pupils' conceptualizations are explored and analyzed on their own terms without assessment against an externally defined system." (p.63).

The epistemological questions raised by this research have promoted an active exchange of ideas. What is perhaps most significant is that the research program on students' conceptions has itself represented an epistemological shift on the part of the community. What had begun as an examination of students' beliefs led to a reexamination of the subject matter, the evolution of the discipline, the conduct of the studies and the conceptualization of the classroom as a place in which knowledge is communicated.

Metacognition Within this community some emphasis has been given to the metacognitive elements of knowing. These researchers have expressed concern with not only what a student believes, but with the student's awareness of that belief system. Captured succinctly by Novak and Gowin's phrase, *Learning How to Learn* (1984), the research in this area often documents how difficult it is for students to describe their beliefs, their methods or their processes for solving problems. Whimbey and Lochhead (1980) developed methods to increase students' awareness of their own knowledge in their methods of paired-problem solving. Other approaches include small group work and the development of written thought protocols by students. Confrey and Lipton (1984) argued that if students' awareness of their own beliefs and methods increase, then many of the student difficulties would disappear, allowing teachers the opportunity to address the more resilient misconceptions rather than the disturbing overall level of poor engagement.

Cultural and Social Dimensions A small segment of this literature is explicitly concerned with the cultural and social dimensions of misconceptions. As reported, Hewson (1985) explored the conceptions of heat of natives of Sotha and found interesting correlations between their cultural and cognitive beliefs. In other cross-cultural work, researchers have studied the use of arithmetic and measurement in third-world workplaces and found significant discrepancies between the formal and informal performances of the workers (Love, 1977, Carraher, Carraher and Schliemann, 1985).

More recently, some work has been undertaken in which the researchers have examined the culture of the classroom and related its structure to the development and dominance of certain cognitive traditions concerned in particular in its impact on ethnicity, gender and class (Confrey, 1984, Cobb, 1985). However, in general the research on misconceptions has remained primarily cognitive, and has had a limited concern for cultural and social dimensions.

Summary. In the previous section, I have identified the themes in the research on misconceptions which have been examined in science education. The purpose of the summary is to introduce this set of categories to mathematics educators in hopes that they will provide encouragement for consideration of parallel issues.

Mathematics Education

In mathematics, the evolution of a misconceptions tradition has been much slower. Without a recognized role for sense-data, education in mathematics lacks the interplay between the sense-data and theory where misconceptions were first described. Without a curriculum in which phenomena and events are explained, researchers were not witness to inconsistencies in mathematical and everyday reasoning. The legal tender of mathematics classrooms was not laboratories and demonstrations, but problems and exercises. As a result, the focus in mathematics education research was on errors.

If one looks for a misconceptions tradition in mathematics parallel to the one in science, it is difficult to find. The issues of preconceptions, structure of concepts, informal and formal uses of language, analogy, history, epistemology, metacognition and social and cultural dimensions of cognition show evidence of only a few dimensions, although a few specific examples exist.

The Clement work described in phase one examined the translation between mathematical symbols and applications, and in that sense, it did create the interplay described above. However, in it, there is not a specific significant concept which underlies the research (although the concept of ratio and variable could have acted in such a capacity if the focus were changed). Little direct attention is given to the language, although a student of Clement, Rosnick (1981) extended the work in this direction focusing on the tendency for students to treat variables as "undifferentiated conglomerates". Other work on these same problems by Sims-Knight and Kaput (1983) built from this research exploring the relations between imagistic and linguistic representations. They concluded, "This confirms that the difficulty lies in mapping from natural representations to mathematical ones" (p 480). In their discussion they offer one of the few explicit statements on misconceptions (as they reject its label as a misnomer) writing, "The tendency to translate '6 students' to '65' is actually a naive theory that students have legitimately developed through their previous experiences in both the natural quantitative world and in mathematics, which they then generalize inappropriately to a new situation." (p 486)

Confrey (1980) in a study of entering calculus students' concepts of number argued for the historical precedence for six distinguishable conceptions of number, sets, ordinal, ratio, number lines, non-terminating decimals, and continuous number concepts and argued that changes in students' concepts from discrete to continuous were necessary to understand the concepts of calculus. Within the study, she examined two epistemological issues, a perspective on mathematics using conceptual change drawing from the work of Lakatos and Toulmin and an investigation into the conceptions of mathematics of the students.

Vinner's work on functions (1983) can also be cast relatively easily within the misconceptions tradition. He proposed that concepts have both "images" and "definitions". He suggested that the definition and the image may be coordinated, be kept isolated or be conflicting, and that students failure to perform in consistent and insightful ways on a series of problems on functions might be the result of conflicts and lack of coordination between definitions and images. In this work, he defines a concept image as as the mental picture of a concept. He wrote, "P's mental picture of C is the set of all pictures that have even been associated with C in P's mind." (p. 293). He added that by picture, he meant to include any unusual representation of the concept, including symbols.

Other work which focused on specific concepts included Schwartzburg and Tall's work on calculus (1975-8), Vinner's and Cornu's work on limits (Vinner, 1983; Cornu, 1983), Steffe, von Glaserfeld, Richards, and Cobb's work on early number (1983), Vergnaud's work on multiplicative structures (1983), Behr, Lesh Post and Silver's work on rational number (1983), and Kitchner's (1985), Kieran (1980) and Matz's (1979) work in algebra. Researchers who have emphasized the historical and epistemological dimensions of the research include Papert (1980), Kaput (1979), Brousseau (1983) and Balacheff (1985). More recently with the introduction of the journal, *For the Learning of Mathematics*, Wheeler has promoted considerable discussion in this area.

Not all epistemological examinations have been historically or psychologically initiated. Mathematicians such as Henderson (1981),

Davis and Hersh (1981) and Stoltzenburg (1984) have called for revisionary views of the discipline of mathematics, wherein the building of mathematics is given attention and where its tentative, evolving and controversial qualities are displayed and celebrated. In a more recent article, Tychemko (1986) has argued for examining the way mathematics act as a community to understand epistemological questions and suggested that one such public occasion for study might be how mathematicians educate their own initiates.

Within the work on errors, mathematics educators have the potential to offer new insights to science educators within the students' conceptions field. The major of themes will be described in the next sections with the provision of a middle level perspective between the specificity of the single concept work and the global character of the epistemological beliefs. This perspective in mathematics education can be described as the systematization of knowledge into a coherent and self-reinforcing structure. It involves the students' strategies for establishing procedures, for carrying out algorithms, and for working with symbolic representations. As a result, it represents a process-based research that cuts across concepts and can be used to predict errors in a variety of arenas. Its weakness is in its isolation for its concepts, its strength is its generality.

Procedural vs. Conceptual Knowledge: A major issue in mathematics education research has been on the relationship between procedural (or algorithmic) and conceptual knowledge in mathematics. Skemp (1980) has contributed the concept of instrumental and relational knowledge to the discussion, in which he suggested that instrumental knowledge dominates the classroom. Davis, Jockusch and McKnight (1978) have created an elaborate information processing grammar to describe the variety of processes required in the construction of mathematical thought and in doing so, have examined in detail the kinds of procedural structures one would have to develop to move fluently through algebra. Although researchers bemoan the general tendency to overemphasize the procedural in mathematics classroom, there is increasing evidence that such facility must be gained through manipulation, computation or the use of tools to allow students the freedom to consider the less accessible conceptual issues.

Systematic Errors: In the widely-known work of Brown and Van Lehn (Van Lehn, 1980; 1983,) the terminology of slips, systematic errors and bugs are introduced. In a 1980 paper, Van Lehn offers definitions of each: A slip is an "unintentional, careless mistake in that a little extra care apparently makes them disappear." (p. 6); a systematic error is "a testable prediction about what new problems a student will get wrong" (p. 6) and a bug is defined as follows:

Once we look beyond what *kinds* of exercises the student misses and look at the actual answers given, we find in many cases that these answers can be precisely *predicted* by computing the answers to the given problems using a procedure which is a small perturbation in the fine structure of the correct procedure. Such perturbations serve as a precise description of the errors. We call them "bugs". (p7)

In this same article, Van Lehn continues to explain how the bugs are used within a larger framework which he calls "Repair Theory". Van Lehn wrote:

Repair Theory is based on the insight that when a student gets stuck while executing his possibly incomplete subtraction procedure, he is unlikely to just quit as a computer does when it can't execute the next step in a procedure. Instead the student will do a small amount of problem solving, just enough to get "unstuck" and complete the subtraction problem. The local problem solving strategies are called "repairs" despite the fact that they rarely succeed in rectifying the broken procedure.... they result in a buggy program. (p9)

The insight that in human beings, as opposed to computers, *the program runs* despite bugs is a significant and often overlooked issue in misconceptions work. The point is that the misconceptions can cause certain conceptual barriers in the learning of the concept; however, failure to work through these barriers does not necessarily result in termination of the attempt to reach a goal. The student will simply turn

elsewhere in an effort to complete the task.

However, it is also essential to stress that the work to date on Buggy is not representative of misconceptions research. It is strictly at the procedural level, and as such, it fails to address some of the epistemological, language and structural questions raised within that tradition. It is not about students' conceptions, only about the routines they use in attempting to complete arithmetical exercises. Were the researchers to embed these classes of problems into word problems, or to explore the underlying concepts such as place value, the conceptions of students would become an obvious factor. This criticism will come as no surprise for the researchers, for they are candid in their reasons for selecting multidigit subtraction:

The initial task chosen for investigation is ordinary multidigit subtraction. Its main advantage, from a psychological point of view, is that it is a virtually meaningless procedure. Most elementary school students have only a dim conceptions of the underlying semantics of subtraction, which are rooted in the base ten representation of numbers. When compared to the procedures they use to operate vending machines or play games, subtraction is as dry, formal and disconnected from everyday interests as the nonsense syllables used in early psychological investigations were from real words. This isolation is the bane of teachers but a boon to the psychologist. It allows one to study a skill without bringing in a world's worth of associations. (p201)

In research with college students, Confrey and Lipton (1985) found that students' performance on relatively simple problems designed to elicit misconceptions could not be reliably tied to those misconceptions. They reported:

...we thought of misconceptions as a system of beliefs which formed a relatively stable and internally consistent cognitive system. We expected misconceptions to be concept-specific and able to be analyzed into prerequisite skills, definitions, representations, related concepts and

the use of language. Furthermore, we expected students to be highly confident of their answers and committed to them. Our data showed that students often applied repetitive and predictable faulty strategies, but these lacked the compelling nature or internal consistency of misconceptions. This suggested the more elementary notion of systematic errors. Systematic errors include the systematic (and inappropriate) application of familiar fragments of arguments, algorithms and definitions without any attempt to integrate across representational systems. They are common across students, and permit accurate predictions of what answers students will give to a set of well-defined problems. (p. 40)

The relationship and distinctions between systematic errors and misconceptions seems to be key in the pursuit of this work in mathematics education. Without a theoretical base which relates procedural and conceptual knowledge in a way which legitimizes both, no resolution to these issues seems possible.

Frames: Recent work by Davis (1980) on the concept of frames seems to provide one attempts to bridge the kind of systematic errors work with the work on misconceptions. In his paper, he distinguishes two kinds of mathematical ideas: "thought processes that are essentially sequential and consist of 'more primitive' steps" (p.169) and frames, "a specific information-representation structure that a person can build up in his or her memory and can subsequently retrieve from memory when it is needed." (p.170) After giving some examples of frames which include the Buggy work, the work of Matz in algebra and the Clement-Lochhead-Rosnick work, he offers a set of characterizations of frames. These are:

1. They serve as "assimilation schemas for organizing input data.
2. Their inner workings are revealed by the errors they produce
3. They were "correct" in a more limited setting
4. They demand certain input information and will not function correctly unless all of this input information is provided
5. They are persistent
6. Their creation and operation follows orderly rules

7. Their retrieval may be cued by brief, explicit, specific cues.
8. For successful problem solvers much information is not contained in the problem statement.

There is a reasonable amount of similarity between the concept of frames and the concept of misconceptions, enough to suggest that this work, although it's relations to a conceptual basis are lacking, begins to postulate something more systemic than a bug, but which has a place for procedural competence.

Constructive Processes and Mathematical Abilities: In the Confrey and Lipton (1985) work, a call was made for the consideration of "constructive processes" in misconception research. In this paper, the researchers reported that students with systematic errors also lacked confidence, did not reformulate the problem, had difficulty describing their methods and focused heavily on the answer rather than the process. Generally, the successful students engaged in another constructive activity when asked to review their solutions. The less successful students routinely reported their methods. Working with the abilities of Krutetskii (1976), these researchers are pursuing the ability to discern the mathematical structure in a problem, the ability to reverse, curtail, generalize and the flexibility to work with multiple methods as the type of constructive processes they would expect to see with students who could successfully work through the lure and appeal of the problems designed to elicit misconceptions.

Next to mathematics and science, studies of novices learning to program use the language of the misconceptions paradigm. Within this tradition, there are three emphases which seem particularly useful in reconceptualizing misconceptions research.

They are:

1. an emphasis on planning as an anticipatory act,
2. an examination of the activity of debugging, as a check and feedback mechanism, and
3. a constant appraisal of the adequacy of the computer language itself as a representational system for human cognition.

An example of such work is offered by Bonar and Soloway (1982, 1985), Erlich, Soloway and Abbott (1982), Solway, Bonar and Ehrlich, (1983), Soloway, Ehrlich, Bonar and Greenspan (1982) and Soloway, Lochhead, Clement, (1985) who have examined novices errors in learning to program in Pascal. In their earlier research, the authors were focused on bugs and buggy procedures. Like the researchers in science education, they believed that errors were illuminating and wrote: "bugs and errors illuminate what a novice is actually thinking--providing us a window on the difficulties as they are experienced by the novice."

One the issues reported in this study is that the students tend to bring to programming knowledge of their "natural language" (i.e. their first language) which could interfere with the definition of the terms in the programming language such as "WHILE". Interestingly enough, since programming languages have developed relatively recently and new ones are constantly under invention, the authors recognize a constant potential for revision of the programming languages itself. This is in sharp contrast to mathematics, where revision of the language in response to user difficulty is unlikely, especially when the users are students. Such a freedom to reconceptualize the language itself provides an interesting challenge to mathematics and science researchers. It suggests they might consider altering the formal

representational systems, which is exactly what is happening in the development of software in mathematics education.

Finally, because there is a human-machine interaction, i.e. a program can be planned, written, run and debugged over time, the programming researchers have devoted considerable attention to the problem solving process. Perkins, Hancock, Hobbs, Martin and Simmons (1985) studied high school students learning BASIC. They expected to call students' attention to the high level problem solving strategies required for managing the task. Instead they found specific management strategies in place which interfered, just as the preconceptions interfere in the correct performance on misconceptions tasks. They wrote: "far from being haphazard and unpatterned, many students' management of the task showed strong patterns that interfere both with the immediate programming problem and with learning." (p.6). These patterns included disengagement from the task at the first sign of trouble, neglecting to track closely by following their own code, repairing haphazardly rather than systematically and experiencing difficulty breaking the problem down into components.

The researchers at Yale, Soloway and colleagues (1985), have shown their intention to pursue problem solving as well by extending beyond patching strategies for bug generation into an attempt to build a "*process model*" of novice program generation. Through this, the authors hope to begin to explain *why* the students make bugs. Although the work is only beginning, the authors offer an enticing statement of their expectations, "instead of a single representation system and a powerful inference method, numerous fragmented representations of knowledge and many weak problem solving strategies may be required." (p.1).

Phase 3: Dredging and Channelling

The final section of the paper is devoted to exploring directions in which the research on students' conceptions might proceed. These directions will be drawn largely from the

themes which emerged from the prior sections, and from the suggestion that a cross-fertilization across the subject matters would prove desirable and worthwhile.

A second influence on this final section of the paper is the theory of constructivism (Confrey, (1983); von Glaserfeld, (1984); Steffe et al. (1983); Cobb, (1985)). Elsewhere, constructivists have argued that the teaching of subject matter is not the transmission of information about 'the way things really are', but that teaching is the communication and development of knowledge that humans find useful and functional in making sense of experience and solving problems. If this position is accepted, then misconceptions are not the result incorrect portrayals of the way things are; they are not failed pictures of the world.

If one rejects the idea that misconceptions result from an incorrect picture of reality, then the question is left, what are misconceptions? In the previous sections, I have suggested that the research on students misconceptions has been successful in defining a variety of the important issues on misconceptions: different symbol systems (including language and analogy), interactions between observations and theories, historical precedence, epistemological beliefs, metacognitive awareness and the social construction of knowledge. I have suggested that the research in mathematics and computer programming has added to this the issues of systematic errors, frames, planning, debugging and the adaptive continuity keeping going. In the following sections, I will use these valuable insights to redefine the conception of misconceptions under a constructivist perspective and suggest a variety of themes which might merit further investigation.

A most important issue for a constructivist is the rejection of **knowledge** of an external world; for a constructivist, we are captives of our constructions, yet by modelling and theory-building we develop effective ways of functioning effectively in the world. A relativistic and solipsistic position is avoided by two forms of activity: self-reflection and communication with others. Through these two activities, we

construct and coordinate a complex system of knowledge, and we evaluate it by reflection on its power to explain our actions and the actions of others.

Thus, a constructivist is bound to reject the external-internal conflict as an adequate source of misconceptions, s/he would therefore revise both the definition of alternative frameworks quoted earlier by Driver and Erickson (1983) and such a statement as the one by Davis (1980) quoted below eliminating any appeal to an external reality to adjudicate among knowledge structures.

"The main method is to show that certain human performances that seem, at first sight, as surprising or paradoxical actually become reasonable (or even predictable) when one assumes certain attributes of frames, assumes the existence of certain specific frames and applies systematic rules of information processing. This kind of analysis usually works best when applied to wrong answers, or to information processing that has malfunctioned. There is no mystery in this. When people agree on a correct answer, many explanations are possible, based primarily on external reality; but when people agree in giving an answer that is wrong, or even grotesque, explanations must deal not only with the external reality that fails to support such an answer, but with the specific internal information processing that somehow produced it. (p. 170)

A radical constructivist would dismiss the appeal to an external reality, though s/he would readily support Davis's intent. If one wants to know more about knowledge, Davis seems to argue, ask the people who claim to know and the student who is coming to know. These are the sources for determining what is knowledge, not the external world.

The constructivist is committed to the claim that knowledge is both tentative and fallible in relation to its level of functionality, situations and contexts change, hence the viability of knowledge changes (von Glaserfeld, 1984). Always, knowledge

is silent in relation to "the way things really are". Thus, the alternative for the constructivist is to express clearly that all forms of human knowledge are our personal constructions and that the question at hand is how does one coordinate, rank or reject and modify these constructs.

Thus, the constructivist does not support the claim that all knowledge is equally valid, certain, stable or supportable. Some knowledge claims are central and relatively stable (though not permanent) and others can be sacrificed rather easily. For the constructivist, a misconception is identified when a relatively stable and functional set of beliefs held by an individual comes into conflict with an alternative position held by the community of scholars, experts, and teachers as a whole. A misconception occurs when there is evidence in what a student says or does that the individual finds the stable belief system more attractive and functional than the alternative view which is offered. Thus, to understand a students' misconception, erroneous only from the perspective of the more initiated, one needs to understand its context, its scope, structure and functionality from the perspective of the student. Thus, the decision on the part of some researchers to use the term, alternative conceptions, is based on their desire to offer validity to the students' framework from the students' perspective.

The Observer is You. Two implications of renaming 'misconceptions', 'alternative conceptions' need consideration. The first is a claim that an essential commitment must be held by the interviewer to attempt to model the student, so that when a student gives an answer which appears to deviate from the widely-agreed upon notions, it will not be rejected out-of-hand, but explored as a crucial research event. Through these explorations, the interviewer creates a model of how the student might be operating. This process is, in a sense, giving an epistemological validity to the students' construction; a validity which seeks to define its frame of reference, the bounds of the context, and its internal consistency.

However, I believe that a distinction must be maintained epistemologically between the personal validity of a construct

and the public approval which has been granted to it. It is a grave mistake to grant a students' work the same epistemological status as its granted to a conception supported by working mathematicians and scientists., just as it is a mistake to rule out of hand that such status might ultimately be conferred. Students are very clever when you learn to listen to them, but the ideas are often rough and underdeveloped.

Thus, the term misconceptions can be misleading in that it connotes a negative interpretation of error, when the only error might be a limited frame of reference beyond which the student has no experience. Alternatively, alternate conceptions frequently connotes a kind of relativism which is unsatisfying in that it seems to ignore the legitimate authority of the disciplinary experts. Thus, it seems that there exists a frame of reference question, in which one needs to reposition the role of the observer.

The observer, be it researcher or teacher, is the one who is evaluating whether a students' responses indicate agreement with the community of experts. It is from the perspective of the observer, that a students' conception might be labelled a misconception or a limited conception. Research results which seek to remove or hide the role of the interviewer reinforce such confusion. We need to reinsert the observer into the pattern of communication, stressing that it is from his or her perspective that a response seems deviant. Thus, by specifying the perspective and the frame of reference, one can describe one's model of a students' active system of beliefs.

The Role of the Discrepancy. It is perhaps useful to remind ourselves that discrepancy plays a key role in communication. Watzlawick (1976) and others have documented that conversation, of which an interview is one form, often continues on the assumption of shared understanding. When an exchange becomes problematic suddenly, it can turn out that the assumption of shared understanding was in error. Interviews are largely dependent on these occurrences to assist in model building. Often we can find ourselves more certain about those interruptions than about the unscrutinized exchanges. Thus, our

picture of a communication is often created first through the shading, and the form emerges. If this is so for the interview, then the discrepant result holds a position of influence in our work which needs to be considered.

Autonomy and Engagement. Another fundamental issue in the redefinition of this research is the emphasis on the autonomy of the student. Numerous studies have documented the tendency, often endorsed and exacerbated by schooling, of students to give up their authority and responsibility for their own learning. In such situations, the search for students' conceptions (limited or alternative) will be lost in the flood of fragments of rules, procedures, assertions, shifts in opinions and general lack of engagement. Documenting these weak and fragmented pieces of memorized and performed routines will not assist one in understanding how concepts are formed, though they may be essential to understanding schooling as it now exists. As a result, researchers must create circumstances in which the student is engaged, does trust the interviewer and is engaged in learning the concept, or perhaps reject the assumptions that robust conceptions are primarily responsible for poor performance. One such option is to conduct teaching experiments or teaching interviews in which the student works with the interviewer over significant periods of time on the concept at hand.

Mathematics Evolved from Actions

Thus, for a constructivist, all the mental material of constructions, from the relatively stable and agreed upon content of an observation as a single event located in space and time to the abstractness of a theory or a symbol system, is the result of human activity. It is built from our previous experiences and serves an important purpose in ordering and allowing for prediction of future events. In a person's experience, constructions have been created to meet personal demands and needs and they are maintained if they function successfully. An essential part of maintaining a construct is assessing how well it allows us to communicate to others, so that construction is

not a solitary affair.

This idea suggests that mathematics is not isolated from humanity, and that it is essentially abstracted, not from things, but from actions. As was pointed out by philosophers of mathematics, the threeness in three apples is not a property like their redness. It is not a property of the apples at all. It is the repeated action of pointing and naming known as counting which establishes the threeness. Human activities, ordering, counting, comparing, sharing, transforming, sorting and relating are the basis for the development of mathematical ideas. As Hermaine Sinclair(1987) explained:

The children pull little bits of cottonwool from a big ball until it is reduced to many tiny flecks. They carefully observe the way the cottonwool stretches and then breaks. Then they make them stick together again; and start all over. ... It does not seem too audacious to see in these activities the very beginnings of counting and measuring. (p34.)

However, an action is not a piece of mathematics. A repeated, intentional action, a pattern of activity, a routine begins to form the basis of the construction of mathematics. When that action becomes abstracted, when it can be described and separated from the objects on which it is conducted, it begins to be mathematical. When the mathematics can be reflected upon and described, it can then become itself a type of object: a mathematical object, timeless and spaceless in that it is a potential action, a possibility. But it is an object in that it has an agreed-upon name, a function and by "objectifying" it (Confrey, 1985) it can be scrutinized in itself. Von Forester (1984) in Observing Systems wrote, "objects and events are not primitive experiences. Objects and events are representations of relations."(p261).

For example, the concept of slope in mathematics requires that one compare two distances, the change in the ordinate and the change in the abscissa. Although we speak in mathematics of slope as a conceptual object, it is only an object in that it is a codified action, that of constructing measures, comparing those measures to create a measure of change and then dividing those

changes to create a ratio and interpreting it through a system of ratios. In mathematics, each concept can be described as such an action on other concepts.

Working from the abilities proposed by Krutetskii (1986), I would propose that a set of constructive processes be developed which were on a continuum from actions to produce procedures and skills consistently to actions which will promote conceptual development. Briefly, I would propose that skills such as pattern recognition, curtailment and reversibility are required for the formation of the procedures, and that generalization, identification of variables, abstraction, particularization, flexibility and elegance represent some of the constructive processes for conceptual development.

How does this conception of the relationship of acting and knowing relate to the second phase of students' conceptions research? It suggests that the relationship between experience and formal knowledge is artificially broad. It suggests that the roots of concepts which lie in human activity need to be drawn more explicitly, and to do so would lessen the separation between formal and informal knowledge. Informal knowledge is often embedded in action; formal knowledge is often abstracted from it. It suggests that this is the case for mathematics as it is for science due in part to an emphasis on the functionality of concepts.

It further suggests that cultural influences on the development of concepts from activity would be expected in different settings, contexts and cultures. A child's activity, labelled "play" differs qualitatively from adults. Their mathematics might vary similarly. Across cultures as well you would expect differences in forms of human activity and their mathematics might evolve differently as well. Finally, it suggests that the similarity of the knowledge might evolve from the similarity of basic human needs.

Coordination of Multiple Representations

If single actions and reflections on those actions constituted the

entire picture, mathematics would be limited indeed, and the exquisite structures and complexities of mathematical and scientific knowledge would not have evolved. If knowledge is not an increasingly better picture of the world, one might ask from where the impetus for progress in science and mathematics comes. Part of that impetus comes from the activity of coordinating these reflective abstractions of actions, which I will call representations. A representation will not refer to that which represents the way things really are. A representation will mean a system of operating which involves a set of codified, objectified actions, and a language or symbol system for communicating about them.

Much of what evolves into knowledge then involves coordinating and moving among representations. For instance, if one investigates the concept of function, one needs to examine how students can use the multiple representations of tables, graphs and equations to solve problems. This coordination of systems is what promotes the stability of mathematics, for in the absence of an appeal to reality, convergence among systems of representation functions effectively.

Thus, I will suggest that in the third phase of students' conceptions research, the issue is one of how students coordinate their representations and how they choose among them in competing circumstances. Vinner's work on concept images fell into this category. In a recent paper, Vinner and Davis (1985) suggest that "...partially equivalent terms to 'concept images' are 'frames' by Davis (1984) and 'students' alternative frameworks' by Driver and Easley (1978)." (p.2). Dicesa, (1979) anticipated this emphasis on multiple representations in his 1978 paper in Cognitive Process Instruction. Recently, the work of Schwartz (1987) and Kaput (1987) and Thompson and Thompson, (1987) in designing software to coordinate the use of the algebraic and graphical representations seems to recognize the importance of this idea. Schuster's research on students' difficulties with various representations, graphs, tables, diagrams, etc. shows the promise in this area. The work of Confrey and colleagues (1987) at Cornell University teaching precalculus students to move flexibly among multiple representations represents this

perspective as well.

Connecting this idea with the research in the second phrase proves useful as well. This suggests that another source for limited or alternative conceptions is in the interplay between representational systems. Language is a key representational system, its place in our educational system is as the glue which joins other systems, through it is itself a system. Thus, the emphasis on the meaning of words across systems, natural language systems and formal systems (mathematical, programming etc.) is a likely source of tension and insight. The work done on the structure of conceptual systems will need expansion as each concept can itself be modelled as a system, an embeddedness that needs no escape. Finally, it suggests that the decision making process of deciphering which representational system to use, when to abandon it, how to coordinate convergence findings, how to resolve conflicting ones, will give rise to the very epistemological issues raised in the prior sections.

What's Missing: The Problem. A area which has been inadequately addressed in the second phrase of research is the question: what is a problem? In a talk on problem solving, I suggested a problem is a "roadblock to where you want to be." Researchers on students' conceptions have been brilliant at writing interesting problems; little analysis or description of the role of the problems in research has been forthcoming. In mathematics, it is clear that the problem plays a key role both in the evolution of the discipline and in the conduct of classrooms.

Researchers rely on problems to create the impetus for the interview; they target problem difficulty to challenge students without frustrating them into inaction; they embed problems with the possibility of multiple pursuits and they attempt to evoke the errors or misconceptions they seek to examine.

Since much of human's activity of "noticing" begins when there is a perturbation in the otherwise constant flow of stimulation (vonForester, 1984) one might consider if the problem acts as such a perturbation in cognitive activity. Successfully creating a perturbation, a sense in a student that here is something to work

on, to attempt to resolve or make sense of, seems to be a key act in the research on students' conception and in education more generally.

A distinction needs to be drawn parallel to the distinction about the assessment of the conception. Just as a conception needs specification of perspective, so does the problem. What is written on the paper may be called the problem, but to assume that a student is working on the same issue as a researcher or teacher has been shown repeatedly to be unsupportable. To distinguish, the word *problematic* can be used to refer to the students' meaning and the word *problem* can refer to the particular public form, written, verbal utterances, experimental, of the problem. Often the problematic the student undertakes has little academic substance; it may be "how do I finish this problem and get outside?" or "what is it that I desired by the book, researcher or teacher?"

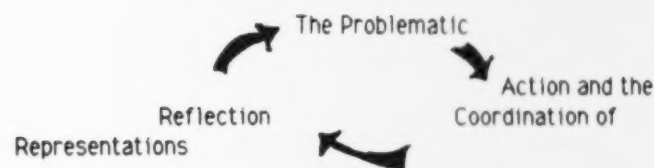
Cycles of Expectation and Reconstruction

A final piece of the puzzle comes from the insight of Brown and van Lehn, that the program continues to run in human beings, where it often halts on a computer. This suggests that there is a cyclic quality to human problem solving, and strategy which allows continuation and resists stoppage. This insight, combined with the pervasive influence of Polya on problem solving leads me to suggest a model for the construction of concepts.

I suggest that a student begins with a problematic, their interpretation of a problem. Since a problematic involves a desire to resolve it or to bypass the roadblock, it creates a "situation for action" (Brousseau, 1983) When the individual acts to solve the problem, s/he may draw upon existing knowledge, representations and experience; before these actions can be accorded the label of knowledge they must be organized by us through the use of representational systems which allow us to *reflect* on our ideas and to *communicate* with others. Our actions become "objectified" through the use of these systems and through their coordinations. Such activity is useful and essential in forming concepts and in routinizing and automatizing

Part of the function of the activity of reflection is to judge if the problematic has been resolved. It is unlikely that any significant insight will be gained by a single action or reflection. The model has been used to analyze interview transcripts, (Confrey, 1987), the resolution of interesting problems typically took a number of passes.

The cycle below serves to capture this cyclic activity:



A Reconceptualization of Misconceptions

Given this cyclic model, I wish to make the fundamental claim of the paper, a limited student conception does not require the postulation of an inadequate "picture" of the world. It does require that a set of beliefs have been developed which allow the student to establish a problematic, act on it to attempt to solve the problematic and to reflect back on the action and coordination of representations to create a new object/tool for future activity because of their success in resolving the problematic. When that set of beliefs appears discrepant from those which are widely held, and when the interviewer or teacher can specify the boundaries of the context in which they are functional, then the student has a limited conception from the perspective of the expert. Possible sources for the limited conceptions include: an artificially distinct separation of concepts from actions, a conflict between systems of representations or a set of epistemological beliefs which overemphasize the claim that knowledge is absolute, unchanging and external to human beings.

In research on students' conceptions, this claim suggests that in

future research,

1. contexts must be created where students are encouraged to engage with the concept at a deep level, perhaps through teaching experiments;
2. the role of interviewer as modeller and interventionist must be considered in the conduct, analysis and presentation of results;
3. an attempt must be made to create problems which produce substantively defined problematics for the interviewee and the interviewer must spend considerable effort gaining evidence of the students' problematics;
4. interviewers must encourage student autonomy;
5. as the student acts, interviewers must seek alternative systems of representation to which the student appeals and consider their functioning, their relative importance and their places of conflict;
6. a significant portion of the interview might be devoted to reflecting back on what the student perceives has occurred.

These suggestions are offered in addition to the ideas suggested in phase two, not as substitutes. The attention to language, the consideration of cross-cultural, or within cultural, cross-gender differences, the historical analysis, the structural relations all complement these further pieces of advice. Students' conceptions research has proven itself to be a healthy and provocative tradition of research with a future which promises to be encouraging.

References

- Ausabel, D. Educational Psychology. A Cognitive View. Holt, Rinehart and Winston. 1968.
- Balacheff, N. Processus de preuves et situations de validation. Rapport de recherche IMAG, n528, Grenoble, France, 1985.
- Behr, M., R. Lesh, T. Post, and E. Silver Rational number concepts Acquisition of Mathematics Concepts and Processes (Lesh and Landau, Eds.) Academic Press, N.Y. 1983 p.92-127.
- Bonar, J. and E. Soloway Pre-programming knowledge: a major source of misconceptions in novice programmers. Human-Computer Interaction Fall, 1985.
- Bonar, J. and E. Soloway Uncovering principles of novice programming Research Report #240 Yale University, New Haven, CT, November, 1982.
- Brousseau, G. Les obstacles epistemologiques et les problemes en mathematiques, Recherches en Didactique des Mathematiques 4,2, 1983 p. 164-198 (1st. edition, 1976).
- Bruner, J. S. Process of Education. Harvard University Press, Cambridge, 1960.
- Carraher, T., Carraher, D. and A. Schliemann Mathematics in the streets and schools British Journal of Developmental Psychology 3, 1985, p.21-29.
- Champagne, A. R. Gunstone and L. Klopfer Instructional consequences of students' knowledge about physical phenomena West, L. and A. Pines, Editors Cognitive Structure and Conceptual Change. Academic Press, N.Y. 1985 p.163-188.
- Clement, J. Analogy generation in scientific problem solving. Technical Report, Cognitive Development Project, Department of Physics and Astronomy, University of Massachusetts, Amherst, 1982.
- Clement, J., Lochhead, and G. Monk. Translation difficulties in learning mathematics. Technical Report. Cognitive Development Project, Department of Physics and Astronomy, University of Massachusetts, Amherst, 1979.
- Clement, J. Algebra word problem solutions: analysis of a common misconception. Journal of Research in Mathematics Education, 13, 1982, p.16-30.
- Clement, J. Students' alternative conceptions in mechanics: a coherent system of preconceptions? Helm, H. and J. Novak, Editors The Proceedings of the Misconceptions in Science and Mathematics, Cornell University, Ithaca, June 20-22, 1983 P. 310-315.
- Cobb, P. An investigation of the relationship between first graders beliefs, motivations and conceptual development in arithmetic. Final Report. Purdue University, West Lafayette, IN for the Spencer Foundation, 1985.
- Confrey, J. Conceptual Change, Number Concepts and the Introduction to Calculus Ph.D. dissertation, Cornell University, Ithaca, 1980.
- Confrey J. Conceptual change analysis: implications for mathematics and curriculum. Curriculum Inquiry Vol II, No. 3, 1981, p.243-257.
- Confrey, J. Implications for teaching from the research on misconceptions. Helm, H. and J. Novak, Editors The Proceedings of the Misconceptions in Science and Mathematics, Cornell University, Ithaca, June 20-22, 1983 P. 21-31.
- Confrey, J. An examination of the conceptions of mathematics of young women in high school A paper presented at the Annual Meeting, American Educational Research Association, New Orleans, 1984.
- Confrey, J. and A. Lipton Misconceptions research and the clinical interview Proceedings of the PME-NA meeting October 1985, p.38-43.

- Confrey, J. Towards a framework for constructivist instruction Proceedings of the Ninth International Conference for the Psychology of Mathematics Education, (L. Streefland, Ed.) Noordwijkerhout, July 22-29, 1985.
- Confrey, J. Quantitative Literacy in the College of Agriculture and Life Sciences. A Report to the College, Cornell University, Ithaca, N.Y. 1987.
- Confrey, J. A model of the cycle of construction illustrated using exponential functions. A paper presented at the Annual Meeting of the American Educational Research Association, Washington, D.C. April 20-24. 1987.
- Cornu, B. Apprentissage de la notion de limite, conceptions, et obstacles. These de doctorat de 3^e cycle, Universite de Grenoble I, 1983.
- Davis, R. Cognitive processes involved in solving simple algebraic equations Journal of Children's Mathematical Behavior V. 1, No. 3, 1975.
- Davis, R. The children's mathematics project: an overview of the Syracuse/Illinois component, Journal of Children's Mathematical Behavior Supplement No. 1, 1976, p32-59.
- Davis, R. The postulation of certain specific, explicit, commonly-shared frames. Journal of Children's Mathematical Behavior V. 3, No. 1, 1980 p.167-200.
- Davis, R. The role of representations in problem solving: case studies. Journal of Mathematical Behavior 4(1) 1985, p.85-97.
- Davis R. E. Jockusch and C. McKnight, Cognitive processes in learning algebra Journal of Children's Mathematical Behavior, 2, (1) 1978, 10-320.
- Davis P. and R. Hersh The Mathematical Experience Houghton-Mifflin C. Boston, MA, 1981.
- DiCessa, A. Phenomenology and the evolution of intuition Mental

Models (D.Gentner and A. Stevens, eds) Lawrence Erlbaum Press, 1983.

- DiCessa, A. Knowledge in pieces. Address to the 15th annual symposium of the Jean Piaget Society, "Constructivism in the Computer Age, Philadelphia, June, 1985.
- DiCessa A. On learnable representations of knowledge: a meaning for the computational metaphor In Cognitive Process Instruction J. Lochhead and J. Clement (Eds.) Franklin Institute Press, Philadelphia. PA 1979 p.239-266.
- Driver, R. and Easley, J. Pupils and paradigms: a review of literature related to concept development in adolescent science students. Studies in Science Education, 5, 1978, p.61-84.
- Driver, R. and G. Erickson, Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. Studies in Science Education, 10 p.37-60, 1983.
- Easley, J. A. On clinical studies in mathematics education. Information Reference Center for Science, Mathematics and Environmental Education, Ohio State University, 1977.
- Ehrlich, K., E. Soloway and V. Abbott Transfer effects from programming to algebra word problems: A preliminary study A Research Report; Dept. of Computer Science, Yale University, New Haven CT 1982.
- Erlwanger, S. Case studies of children's conceptions of mathematics--part I; Journal of Children's Mathematical Behavior V. 1, No. 3, 1975, p.157-268.
- Fisher, K., J. Lipson and J. Idar. Information processing interpretations of error research in learning: Part 1: Mental model and alternative conceptions. Helm, H. and J. Novak, Editors The Proceedings of the Misconceptions in Science and Mathematics, Cornell University, Ithaca, June 20-22, 1983 P. 150.
- Gentner, D. The structure of analogical models in science. A

technical report, Bolt, Beranek and Newman, Inc. Cambridge, MA, 1980

Gilbert, J. and Watts, D. Concepts, misconceptions and alternative conceptions: changing perspectives in science education. Studies in Science Education, 10, 1983, 61-98.

Ginsburg, H. Young children's informal knowledge of mathematics Journal of Children's Mathematical Behavior V. 1 No. 3, 1975, p63-156.

Ginsburg, H. The children's mathematics project: an overview of the Cornell component; Journal of Children's Mathematical Behavior Supplement No. 1, 1976, p7-31.

Ginsburg, H. Children's Arithmetic: How They Learn It and How You Teach It. Pro-Ed, Austin, TX 1977.

Gowin, D. Misconceptions, metaphors and conceptual change: once more with feeling. Helm, H. and J. Novak, Editors The Proceedings of the Misconceptions in Science and Mathematics, Cornell University, Ithaca, June 20-22, 1983 p. 39-46.

Hawkins, D. The Informed Vision: Essays on Learning and Human Nature Agathon Press, N. Y. 1974.

Hawkins, D., M. Apelman, R. Colton, A. Flexner A Report on Critical Barriers to the Learning and Understanding of Elementary Science National Science Foundation Contract #SED 80-08581, 1982.

Head, J. and Sutton, C. Language, understanding and commitment West, L. and A. Pines, Editors Cognitive Structure and Conceptual Change, Academic Press, N.Y. 1985 p. 91-100.

Helm, H. and J. Novak, Editors The Proceedings of the Misconceptions in Science and Mathematics, Cornell University, Ithaca, June 20-22, 1983.

Henderson, D. Three papers For the Learning of Mathematics 1(3) March, 1981, 12-15.

Hewson, Mariana G. A The role of intellectual environment in the origin of conceptions: an exploratory study West, L. and A. Pines, Editors Cognitive Structure and Conceptual Change, Academic Press, N.Y. 1985 p. 153-162.

Johansson, B, F. Marton and L. Svensson, An approach to describing learning as change between qualitative different conceptions. West, L. and A. Pines, Editors Cognitive Structure and Conceptual Change, Academic Press, N.Y. 1985 p. 233-258.

Kaput, J. Mathematics and learning: roots of epistemological status In Cognitive Process Instruction J. Lochhead and J. Clement (Eds.) Franklin Institute Press, Philadelphia PA 1979 p. 289-304.

Kaput, J. Information Technology and Mathematics. Opening New Representational Windows Journal of Mathematical Behavior 5,(2)p. 187-208.

Kieran C. The interpretation of the equals sign: symbol for an equivalent relation vs. an operator symbol. Proceedings of the Fourth International Conference for the Psychology of Mathematics Education, Berkeley, CA, 1980.

Kitchner, D. A linguistic model of algebraic symbol skill The Proceedings of the Seventh Annual Meeting of the PME-NA, Columbus, Ohio, 2-5 October, 1985 p. 153-164.

Krutetskii, V. The Psychology of Mathematical Abilities in Schoolchildren, University of Chicago Press, Chicago, IL. 1976.

Lakatos, I. Proofs and refutations: the logic of mathematical discovery Cambridge, England. Cambridge University Press 1976.

Lakatos, I. Falsification and the methodology of scientific research programmes In I. Lakatos and A. Musgrave (Eds) Criticism and the growth of knowledge, Cambridge University Press, Cambridge, England 1970

Lave, J. Tailor-made experiments and evaluating the intellectual consequences of apprenticeship training. The Quarterly Newsletter

of the Institute for Comparative Human Development, Vol 1, No2 February 1977.

Lybeck, L., H Stromdahl and A. Tullberg Students' conceptions of amount of substance and its SI unit 1 Mol. A subject didactic study Report No 1985.04, Department of Education and Educational Research, Gothenburg U. Gothenburg, Sweden, 1985.

Lybeck, L. Research into Science and Mathematics Education at Goteborg Report No 1985.03, Department of Education and Educational Research, Gothenburg U. Gothenburg, Sweden, 1985.

Marton, F. Describing conceptions of the world around us. Report No 1978.66, Department of Education and Educational Research, Gothenburg U. Gothenburg, Sweden, 1978.

Matz, M. Underlying mechanisms of bugs in algebraic solutions, A paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA, April, 1979.

Novak, J. An alternative to Piagetian psychology for science and mathematics education Science Education, 61 (4) 1977 p.453-477.

Novak, J. Metalearning and metaknowledge strategies to help students learn how to learn West, L. and A. Pines, Editors Cognitive Structure and Conceptual Change, Academic Press, N.Y. 1985 p.189-207.

Novak, J. and D. Gowin Learning How to Learn Cambridge University Press, Cambridge, England 1984.

Osborne, R. and P. Freyberg Learning in Science: the Implications of Children's Science Heinemann Portsmouth N. H. 1985.

Papert, S. Mindstorms Basic Books Inc. Publishers, New York, 1980.

Peck, D., Jencks, S. Are common fractions out-of-date. The Elementary School Journal, University of Chicago, V. 80, No.1 1979.

Perkins, D., C. Hancock, Hobbs, R Martin, and R. Simmons Conditions

of learning in novice programmers. Journal of Educational Computing Research, 2(1) 37-56.

Piaget, J. The Child and Reality. Problems of Genetic Psychology New York, Grossman Publishers, 1973.

Piaget, J. Genetic Epistemology New York. Norton and Company, 1970.

Pines, L. Towards a taxonomy of conceptual relations West, L. and Pines, editors A. Cognitive Structure and Conceptual Change, Academic Press, N.Y. 1985 p.101-116

Pope, Maureen Constructivist goggles: Implications for process in teaching and learning. A paper presented at the BERA Conference in Seffield England, August, 1985.

Rosnick, Peter. Some misconceptions concerning the concept of variable. Mathematics Teacher, 74, 1981, 418-420.

Rousseau, Emile (translated by Barbara Foxley) Everyman's Library, Dutton, New York, 1974.

Rumelhart D. and Norman, D. Analogical processes in learning Report No. 8005 Center for Human Information Processing, University of San Diego, 1980.

Schoenfeld, A. Mathematical Problem Solving. Academic Press Inc. New York, 1985.

Schuster, D. The explicit teaching and testing of representations in physics: a course entitled "kinematics and representations" A paper presented at the International Summer School on Physics Education, La Londe Les Maures, France June 26- July 13, 1983.

Schwartz J. The representation of function in the algebraic proposer. The Proceedings of the XI International Meeting of the Psychology of Mathematics Education, Montreal, Canada, July 1987 p.235-240.

Schwartzenberger, R. and D. Tall Papers on Calculus and

Catastrophes Mathematics Institute University of Warwick
Coventry, England 1975-1978.

Sims-Knight, J. and J. Kaput Misconceptions of Algebraic Symbols: Representation and Component Process Helm, H. and J. Novak, Editors The Proceedings of the Misconceptions in Science and Mathematics, Cornell University, Ithaca, June 20-22, 1983 p.477-487.

Skemp, R. Mathematics as an activity of our intelligence. A paper presented at the 7th Annual Conference of the Research Council for Diagnostic and Prescriptive Mathematics, 13-15 April, 1980, Vancouver.

Skemp, R. The Psychology of Learning Mathematics Pelican Books, Middlesex, England, 1971.

Solomon, J. Thinking in two worlds of knowledge Helm, H. and J. Novak, Editors The Proceedings of the Misconceptions in Science and Mathematics, Cornell University, Ithaca, June 20-22, 1983 p. 127-131.

Soloway, E., J. Bonar and K. Ehrlich Cognitive strategies and looping strategies: an empirical study Communications for Association for Computing Machinery, 26, 11, November, 1983 853-860.

Soloway, E., K. Ehrlich, J. Bonar, and J. Greenspan What do novices know about programming? Directions in Human-Computer Interactions, Ablex Publishing Co. 1982.

Soloway, E. J. Lochhead, and J. Clement Does computer programming enhance problem solving ability? Some positive evidence on algebra word problems Proceedings of the Conference on National Computer Literacy Goals for 1985, 1985.

Steffe, L. E. von Glasersfeld, J. Richards and P. Cobb Children's Counting Types: Philosophy, Theory and Application, Praeger Scientific Press, New York 1983.

Stoltzenburg, G. Can inquiry into the foundations of mathematics

tell us anything interesting about mind? The Invented Reality, Watzlawick, editor, W.W. Norton, N.Y. 1984 p.257-308.

Strike, K. and G. Posner A conceptual change view of learning and understanding West, L. and A. Pines, Editors Cognitive Structure and Conceptual Change, Academic Press, N.Y. 1985 p. 211-232.

Sutton, C. Science, language and meaning. The School Science Review 62, 1980, p. 47-56.

Thompson, P. and A. Thompson Computer presentations of structure in algebra The Proceedings of the XI International Meeting of the Psychology of Mathematics Education, Montreal, Canada, July 1987 p.248-254.

Toulmin, S. Human Understanding Princeton U. Press, Princeton, N.J. 1972.

Tymoczko, T. Making room for mathematicians in the philosophy of mathematics The Mathematical Intelligencer 8(3) 1986, p.44-50.

Vergnaud, G. Multiplicative structures Acquisition of Mathematics Concepts and Processes (Lesh and Landau, Eds.) Academic Press, N.Y. 1983 p.128-175.

VanLehn, K. Bugs are not enough: empirical study of bugs, impasses and repairs in procedural skills. Journal of Mathematical Behavior V. 3, No. 2, 1980.

VanLehn, K. On the representation of procedures in repair theory The Development of Mathematical Thinking (Ginsburg, H. Ed) Academic Press, New York, 1983 p.201-253.

Vinner, Shlomo Concept definition, concept image and the notion of function. International Journal of Mathematics Education, Science and Technology Vol 14, No. 3 1983, 293-305.

Vinner, Shlomo and R. Davis The concept of limits Journal of Mathematical Behavior, 4, (2) 1986.

von Glasersfeld, E. An introduction to radical constructivism The

Invented Reality, Watzlawick, editor, W.W. Norton, NY. 1984.
p14-40.

von Foerster, H. Observing Systems Intersystems Publications,
Seaside, CA 1984.

Vygotsky, L. Mind in Society (Edited by M. Cole, .V. John-Steiner,
S. Scribner and E. Souberman) Harvard University Press, Cambridge
1978.

Watzlawick, P. How Real Is Real? Vintage Books, New York, 1976.

Weaver, J. and J. Kilpatrick The place of meaning in mathematics
Instruction: selected theoretical papers of William A. Brownell
Studies In Mathematics, Vol XXI Stanford University, 1972.

West, L., P. Fensham, and J. Garrard Describing the cognitive
structures of learners following instruction in chemistry. West, L.
and A. Pines, Editors Cognitive Structure and Conceptual Change,
Academic Press, N.Y. 1985 p.29-48.

West, L. and A. Pines, Editors Cognitive Structure and Conceptual
Change, Academic Press, N.Y. 1985.

Whimbey A. and J. Lochhead Problem Solving and Comprehension
Franklin Institute Press, Philadelphia, PA 1980.

White, R. Interview protocols and dimensions of cognitive
structure. West, L. and A. Pines, Editors Cognitive Structure and
Conceptual Change, Academic Press, N.Y. 1985 p. 51-60.

THE COMPUTER IN CREATIVE MATHEMATICS

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As education has expanded to include all the children, it has concentrated on basic knowledge needed by all people and, inevitably, the special interests and abilities of gifted and talented children were not served. This project, "The Computer in Creative Mathematics," is one of many attempts made by many people through many years to provide a more equitable curriculum.

We plan a longitudinal experiment of at least five years. We have completed three trials: 10 weeks in each year, 1985, 1986, 1987, with a different group of students each year.

Underlying the project are a number of beliefs and assumptions related to the education of the gifted and talented. As we designed this project we have tried to implement these beliefs for the purpose of challenging and encouraging our youth.

We believe:

- * Many potential talents lie dormant, unsuspected and undeveloped in many people; the human brain is being only partially used.
- * Giftedness is often highly specialized; a person gifted in poetry may not be gifted in mathematics, a gifted mathematician may not be a gifted artist.
- * To locate gifted persons, we must cast our nets widely in unlikely as well as likely places - a democratic principle which gains the support of the public.
- * Students gifted in mathematics thinking can grasp meanings and concepts and can create new ones.

- * The persons most likely to detect giftedness and to provide for its development are the masters in each field. In this project, mathematics teachers, very familiar with all their students, selected those students able to conceptualize and likely to be creative.
- * Appropriate opportunities must be provided to allow talents to come to the surface.
- * The computer and LOGO are among the provisions that can assist mathematical thinking because they allow rapid calculation and great flexibility in thought.

The importance of pre-college preparation for careers in science and engineering is just beginning to be appreciated. The present need of the country for technical personnel has brought it to our attention. The Japanese have excelled in transforming our ideas and our designs into useful products because of our relative weakness in engineering. Erick Block, Director of the National Science Foundation, expressed this concern in the February 6, 1987, issue of Science (p. 621) when he includes "better pre-college preparation" among "the approaches we need to employ."

This current project, The Computer in Creative Mathematics, represents an educational strategy which may prove valuable in pre-college preparation. The objective of this project is to determine if students, when provided with a special "liberating" learning environment, can leave "the beaten paths" of the traditional branches of mathematics and discover lines of thought that they have not been taught. The first need was to develop a theoretical framework for an instructional process that would nurture creativity.

PIAGETIAN LEARNING

The educational philosophy underlying this project is largely that of Jean Piaget, renowned child psychologist, International Center for Genetic Epistemology, University of Geneva, Geneva, Switzerland.

He studied how children think. He found that they learn by doing and thinking about what they do. He discovered that intellectual development does not always need explicit teaching, that vast amounts of learning happen without being taught. He observed that knowing (cognition) during child development can precede sufficient command of language to express what is known. This concept provides for intuition and insight.

Piaget indicated also that children need the liberty to free their ideas. Consequently, they should be allowed to direct some of their learning. This learner-directed process, especially necessary for the gifted, gives freedom to their imagination, a chance to make their minds work, and a challenge to their greatest ability. Accordingly, students must be encouraged to "romp creatively" (19 p. 178) with mathematical ideas and to follow their own intuition and insights.

Piaget introduced the new constructivist theory of the development of knowledge, essentially the interaction between the student and new information which he integrates into existing knowledge to form a new structure. In 1977 Piaget said his current research was dealing with the "opening up of new possibilities...the way in which an action, an operation, or a structure acquired by the child generates new possibilities." (24 p. 350) Integration involves many functional mechanisms including assimilation-accommodation, equilibration, reflective abstraction-constructive generalizations, differentiation and integration of sub-systems.

The new structure presents new possibilities, and "every possibility generates new ones." (24 p. 350) The student constructs from what he thinks and what actually happens in reality. As this process of construction is repeated, an ever-wider range of possibilities can be envisaged. Discoveries can originate from this interaction, the result

varying according to the competence and diligence of the student in the creation of new structures and new forms of organization, and the ability to invent the vocabulary to express the new ideas.

Our current project is based upon the potential for creativity in this theory and upon the fact that constructive generalization is thought to be the main mechanism of progress in mathematics. (13 p. 337) We are observing whether the same pattern of interaction between high school students and mathematics prevails as it does between infants and the environment. The levels of abstraction and the types of concepts among high school students may be different from those among elementary children but Piaget has observed there is an increase with age in the number of possibilities perceived. (24 p. 350) However, many mechanisms are common to both age levels.

INTUITION AND INSIGHT

Alfred Bork indicates that intuition can be built, that the goal of education goes beyond "manipulative skills" to "understanding intuitively critical problems or needed directions of advance." (4 p. 69) He says that the intuition we develop in everyday life comes from the rich collection of phenomena we experience. Thus, whenever students can greatly increase and control their experiences they build intuition and open the door to a world of insights. Seymour Papert, mathematician at Massachusetts Institute of Technology, in an interview with Carlos Vidal Greth in 1983, expressed the belief that a "computer poet" could "touch on the deeper non-logical dimensions of self and the personal aesthetic." (11 p. 24)

However, this is not to say that teachers and resources are not needed. For a learner to direct his own learning poses other problems. He needs the help of a teacher who is a specialist in motivation and creativeness. In fact, the teacher is the key to success in non-authoritative instruction. He must have sensitivity and the "light touch" of the artist, knowing just when and how to make

suggestions without diverting the student's own ideas.

Also, the student should have access to scholars and to the most up-to-date knowledge in the field he is investigating.

The "liberating" climate in which the instruction takes place is most important. Acceptance, encouragement and joy in learning appear to produce the environment in which intuition, insights and creativity thrive.

USE OF THE COMPUTER

Once a sound educational theory is adopted the need is to apply it to the learning environment. Most fortunately, the computer is now available to assist the learner-directed process in more than a super-sliderule capacity. It is especially helpful in the study of mathematics because of its great speed in doing calculations and its ability to make graphical representations. A whole universe of ideas becomes available and the computer allows the learner to interact with them.

The methodology to implement the philosophy of this project and to develop the "liberating" climate is largely that of Seymour Papert. He became interested in the learning activities of young children and the use of the computer in their education. He worked with Piaget in France for five years. As a result he has combined child development theory with knowledge of both mathematics and computers and has devised a method of teaching mathematical thinking to young children, teaching them to "mathematize." (19 p. 194) He developed the computer programming language LOGO expressly for teaching children mathematics. LOGO is primarily symbolic and secondarily quantitative. It lends itself especially well to creativity. Papert says that LOGO is "simple enough for a five-year-old" and "sophisticated enough for a computer scientist." (11 p. 22)

LOGO is designed to contain state-of-the-art artificial intelligence concepts such as list processing and recursion. It is a computer language that allows students to start at their own level and yet explore to the limits of their

imagination and satisfy their creative desires.

According to Donald A. Norman of the University of California at San Diego, "LOGO has the virtue of cleanliness, and simplicity combined with elegance and computing power. It is a teaching device...worthy of continued experimentation and evaluation." (17 p. 226) It has been made available only recently. How successful it will be is yet to be determined.

Computer-related technology makes it possible for a student to redefine terms, redesign procedures and tap the new depths of his thought. The computer can be used to add new degrees of freedom to what children learn and how they learn it. Its magic involves creation of new visions of old things. Papert says "the possibilities are endless...there are small discoveries" and "perhaps learning to make small discoveries puts one more surely on a path to make big ones..." (19 p. 190)

Papert says "when 'discovery' means discovery this is wonderful..." (19 p.178) He uses the word in its true dictionary meaning. It is not to be confused with the "Discovery Method" in which the "teacher" has perfected a series of questions that lead the class to "discover" a predetermined result desired by the teacher.

A fundamental problem in creative mathematical education is enabling the student to identify and name the new concepts and to discuss his mathematical thoughts in a clear articulate way. LOGO helps develop the vocabulary necessary for articulate discussion. Papert thinks that in teaching mathematics one should concentrate on teaching concepts and terminology which will enable children to articulate about the process of developing a mathematical analysis. He states "the possibilities for original minor discoveries are great" (19 p. 190) when using LOGO to describe one's own ideas.

Also, Papert has added another dimension to Piaget's ideas. Papert has "expanded beyond Piaget's cognitive

emphasis to include a concern with the affective. It develops a new perspective for education research found in creating the conditions under which intellectual models will take root...feeling, love, as well as understanding..." (20 p.VII) He writes that the critical factor is the relative poverty of the culture. (20 p. 7) He urges "creating conditions for the emergence of computer poets." (11 p. 24) He says "I use the computer in the same way a poet uses words, to touch on intimate and individual aspects of life. (11 p. 24)

THE PROJECT

Piaget himself pointed out that the heart-breaking difficulty in pedagogy, as indeed in medicine and in many other branches of knowledge that partake at the same time of art and science, is, in fact, that the best methods are also the most difficult ones. As we considered the preceding theories and the applications of Papert's ideas in the elementary school, my colleague, Douglas Parsons, agreed to conduct a similar project with a group of high school students in Oneonta, New York. Our task was to create an environment in which the discoveries were likely to occur, to reduce the "poverty of the culture." (20 p. 7) To insure the best possible project we consulted authorities on Piaget, LOGO, mathematics, and education.

We chose to explore in the mathematics area because it depends almost exclusively on brain power and the resources within one's self. Daniel E. Koshland Jr., editor of Science, referred to "programs that need only time for thinking, like some mathematics" (15 p. 589) in contrast to those that need expensive hardware.

We planned to follow what I consider the democratic, as opposed to the elite, procedure for eliciting and developing the gifts and talents in all children: "interest, opportunity and performance" (5 pp. 142-144). As John Hersey observed, "the value of each individual to a democratic society lies precisely in his uniqueness..." (12 p. 13).

Consequently, we are advised to "cast your nets widely in unlikely as well as likely places." (3 p. 18)

The students invited to enter the project were high school juniors and seniors who had had the traditional courses in mathematics and had learned to use computers with the BASIC language. The students had been observed by their teachers to have one special ability in common: the ability to develop mathematical concepts. Krutetskii, a Russian psychologist, referred to these extraordinary gifted youngsters with a "mathematical cast of mind" who need a very special experience to develop these special talents to their fullest. (10 p. 7) Those students who accepted our invitation were enthusiastic about participating and felt it was a great opportunity to follow their interests.

All students had access to IBM PC computers, not only during class but also after school, evenings, and weekends. The computers were used as tools to assist in testing their ideas, to increase the speed of calculations, to plot graphs of mathematical concepts, to control physical processes toward definite goals, and, by means of LOGO, to articulate their ideas and observations.

Students who were already interested in specific problems were encouraged and assisted in pursuing their solutions. For the other students, new ideas in mathematics were introduced such as trying functions other than quadratics in factoring, and trying Penrose tiling to create new designs. Whenever language or symbols to adequately express their insights did not appear to exist, students were urged to invent them. This skill is particularly needed by students gifted in mathematical thinking.

EVALUATION

At the World Conference for Gifted and Talented Children in Hamburg, Germany in 1985 we became interested in the Model for Intellectual Productivity of Dr. J. J. Gallagher (copy attached). He presents six key factors, their interaction and relative importance. In using the chart to

improve our project, we find we are already stressing the two most important factors: ability to master abstract systems 30-50% and opportunities for talent development 10-20%. The remaining four factors are psychological and sociological and we are considering supplementing the project in these areas. For example, we need a way to deal with frustration when the development of an idea seems to reach an impasse. In Dr. Gallagher's chart it is listed as "Self-confidence in Environmental Understanding and Mastery."

Having designed our project to nurture creativity we needed ways to detect it. We decided to examine the daily logs of the students for Polya's "Signs of Progress." (25 pp. 178-190) These signs need not be complete proofs but rather plausible suggestions, analogies, and implications of new information. For example, finding an additional factor that influences a situation and integrating it into the solution of the problem may be "properly felt as progress, as a step forward." (25 p. 182) Even though that solution still needs to be tested and proved, it suggests a direction in which the answer may possibly be found.

We selected criteria by which the performance of the students and the results of the project would be judged:

1. Have the students learned how to use a second computer (IBM)?
2. Have they learned a second computer language (LOGO)?
3. Have they learned to "mathematize" as opposed to manipulating a set of formula symbols and/or figures according to a set of computational rules? Are they better able to grasp the whole situation as opposed to calculating parts?
4. Has the experience in the project enabled them to see their own thinking processes more clearly, to be more critical of them and more constructive in taking the next step? (22 p. 141)
5. Have they learned their "skill for coping" (22 p.

145) by spotting issues and separating the relevant from the irrelevant in a situation?

6. Have any new ideas "just popped into" their heads? (22 p. 139) Did any learning just happen? Has there been any evidence of intuition or "non-logical dimensions?" (11 p. 24)

7. Have the students added anything of their own to the data base? Have they related parts of the data base to each other in new ways? Have they felt free to explore their own ideas?

8. Are there any evidences of affective learning? emotional or aesthetic involvement? fanciful or playful purposes? "feeling, love as well as understanding?" (20 p. VIII)

9. Have they made any "small discoveries," defined as ideas, lines of thought or facts not previously known to the student," in mathematics, education or other fields?

10. Have any of the students made "significant discoveries:" actually new knowledge not previously known in mathematics, education or other fields?

CONCLUSION - A HOPE AND A CHALLENGE

Papert states "the computer has brought us the technological infrastructure that can make possible a real intervention in the learning environment." (19 p. 202) He believes it can even "touch deeper, non-logical dimensions of self and the personal aesthetic." (11 p. 24) He expresses the hope that we "can make the most of it." (19 p. 202) In this project we are trying.

PROGRESS OF THE PROJECT

Evaluating our progress against the procedure, "interest, opportunity, performance " we note the following findings:

SPECIAL INTERESTS OF STUDENTS

In evaluation of the project over three years, there is a question whether our scope in regard to potential

mathematical talent is too limited. We have chosen interested, able students but only those who have already taken the mathematics courses. We are "casting our nets" only in the likely, not the unlikely places. Perhaps, in another project or in an expansion of this one, we should explore interests of all students with a whole class, perhaps all seniors or all juniors or even lower classes.

Beatrice King in "The Educating of the Gifted Child in Bulgaria" observed that "in Bulgaria the concern is not with how to detect talent and ability, but with the provision of opportunities for talent and ability to show themselves, with the creation of demand - situations that will call forth talent." (14 pp. 241-254)

We in the United States have been overly concerned with the selection of gifted students and not sufficiently concerned with the opportunities to "show themselves" except with athletes. Each culture gets the talent it values most. Apparently, this country with its "poverty of the culture" does not yet value the contributions to society the gifted and talented can make. Consequently, we are resistant to providing inspiring situations which serve the interests of children and "call forth latent talent."

OPPORTUNITIES

As for opportunities for the students selected, we have provided the teacher, the computer room, one period with access to the computers within each school day, and one period a week for the students to meet, exchange ideas and brain-storm.

We have indicated that the teacher is key to the success in non-authoritative instruction. In my opinion, my colleague, Mr. Parsons, is adept in this difficult role. Just what do you tell the students? When do you tell it? If you tell them your objectives, will they as usual try to please the teacher? If you help them with ideas, will they ignore their own? If you do not help them, will they flounder and become discouraged for lack of one bit of

knowledge the teacher could easily supply?

Mr. Parsons still found it was good to teach the group some basic skills in the usual way: list processing, recursion, graphics, and other means in LOGO. He used good models and problem-solving methods but the students proceeded largely on their own - finding and exploring possibilities that interested them.

Unfortunately, we have not yet been able to supplement the teacher with mentors who have expertise in various branches of mathematics and can work with individual students.

Finding an interesting question one wants to pursue seems to be the most difficult problem. The choice should be based on the student's own curiosity. Assistance by the teacher may be necessary at this point. The students can be encouraged to reflect on the math courses they have previously studied to see if they questioned or wondered about anything there. Mathematical issues mentioned in the current articles such as randomized response can be brought to their attention. A brain-storming session can be held in which all students suggest questions that intrigue them.

Another problem is the difficulty of freeing one's self from present knowledge and handling it so it aids rather than hinders new ideas. One girl said she had difficulty thinking other than with the calculus she had already learned.

Also, the project each year takes place only 10 weeks during the last quarter. It is the least desirable quarter because of end-of-year activities. However, it is the only time presently available in the school schedule.

PERFORMANCE

In evaluating performance, we have Mr. Parsons' opinion based on his daily work with students and his tests. In addition, we have a very valuable log for each student in which he records his procedures and thoughts each day. Mr. Parsons and I read these very carefully looking for signs

that the objectives were reached including especially unusual ideas and "discoveries."

A caveat in judging performance is to beware of the tendency of students to do whatever pleases the teacher and to "finish" a project as opposed to carrying on an open-ended investigation.

In all phases of this project we value the judgment of experts on the performance of each student.

NEW DIRECTIONS

Every good experiment suggests further investigation. Some of the directions this project has already indicated are:

Can metacognition, awareness of one's own thinking processes be improved so as to lead to more original ideas?

Can curriculum changes be made to provide more time for the development of the unusual talents of each student?

How can we find experts as mentors who will help students interested in their specific fields?

How can we discover the "mathematical cast of mind" when it is existing in a latent state within an individual?

What incentives can we introduce to motivate students to enjoy thinking and doing original work?

If creativity is being stimulated in our project, are the students transferring it to their other subjects and activities?

What traits and skills are desirable in teachers of the gifted?

REFERENCES

1. American Association for Gifted Children. On Being Gifted. New York: Walker and Company, 1978. (The report of 20 talented high school students on their experiences going through school. "We hate the word 'gifted.' 'Talented' we like.")
2. American Association for Gifted Children. The Gifted Child, The Family, and The Community, edited by Bernard S. Miller and Merle Price. New York: Walker and Company, 1981. (A compendium of the best thinking on an environment in which giftedness and talent can thrive.)
3. Anderson, John E. "The Nature of Abilities," Talent and Education. University of Minnesota Press, 1960, p. 18.
4. Bork, Alfred. The Computer in the School: Tutor, Tool, Tutee, Ed. by Robert Taylor. New York: Teachers College Press, Columbia University, 1980, pp. 67-82.
5. Coutant, Madeleine F. "A Constituency for the Gifted and Talented," Gifted and Talented Children, Youth and Adults: Their Social Perspectives and Culture, Selected Proceedings of the Fifth World Conference on Gifted and Talented Children. Ed. by Aurora H. Roldan, Greenhills 3113, Metro Manila, Philippines, August, 1983.
6. Coutant, Madeleine Frink. Cooperative Arrangements Among New York State Schools For the Education of Students With Special Interests and Abilities. New York: Teachers College, Columbia University, 1965. (A source book of ideas and programs from a pilot project of the Ford Foundation Fund for the Advancement of Education.)
7. Dreyfus, H. L. Computer Culture. New York: The New York Academy of Sciences, 1977, p. 145.

8. Dwyer, Thomas A. The Computer in the School: Tutor, Tool, Tutee. Ed. by Robert Taylor. New York: Teachers College Press, Columbia University, 1980, pp. 85-125.
9. _____. "Soloworks" Computer-based Laboratories for High School Mathematics." School Science and Mathematics. 75, 1, January 1975.
10. Gallagher, James J. "Creating the Right Climate for Climate for Giftedness," Gifted and Talented Children, Youth and Adults: Their Social Perspectives and Culture, Selected Proceedings of the Fifth World Conference on Gifted and Talented Children. Ed. by Aurora H. Roldan, 1983, p. 7.
11. Greth, Carlos, Vidal. "Learning to Learn with the Father of LOGO." Atari Connection. 3, 3, Fall 1983.
12. Hersey, John. "Intelligence, Choice and Consent." Education in the Nation's Service, No. 7, The Woodrow Wilson Foundation, July 1959, p. 13.
13. Inhelder Barbel. "Genetic Epistemology and Developmental Psychology." The Roots of American Psychology: Historical Influence and Implications for the Future. New York: The New York Academy of Sciences, 1977, pp. 332-341.
14. King, Beatrice. "The Education of the Gifted Child in Bulgaria," In Bereday, G.Z.F., and Lauverys, J. A., editors, Concept of Excellence in Education, The Year Book of Education 1961. New York: Harcourt, Brace and World, 1961, pp. 241-254.
15. Koshland, Daniel E. Jr. "A Department of Science." Science, 227, 589, February 8, 1985.
16. Minsky, Marvin L. Computer Culture. New York: The New York Academy of Sciences, 1977, p. 139.
17. Norman, Donald A. "Worsening the Knowledge Gap: The Mystique of Computation Builds Unnecessary Barriers." Computer Culture. New York: The New York Academy of Sciences, 1984, pp. 220-233.
18. Papert, Seymour. Computer Culture. New York: The New York Academy of Sciences, 1977, p. 141.
19. _____. The Computer in the School: Tutor, Tool, Tutee. Ed. by Robert Taylor. New York: Teachers College Press, Columbia University, 1980, pp. 159-210.
20. _____. Mindstorms: Children, Computers, and Powerful Ideas. New York: Basic Books, 1980.
21. _____, and Cynthia Solomon. "Twenty Things to do with a Computer." Educational Technology, 12, 4, April 1972.
22. _____ and others. "Panel Discussion: Has Artificial Intelligence Illuminated Human Thinking?" Computer Culture. New York: The New York Academy of Sciences, 1984, pp. 138-160.
23. Piaget, Jean. Science of Education and the Psychology of the Child. New York: Orion Press, 1970.
24. _____. "Some Recent Research and Its Link with a New Theory of Groupings and Conservations Based on Commutability." The Roots of American Psychology: Historical Influence and Implications. New York: The New York Academy of Sciences, 1977, pp. 350-358.
25. Polya, George. How to Solve It. Second Edition. Princeton, N. J. Princeton University Press, 1975.
26. Roldan, Aurora H., Ed. Gifted and Talented Children, Youth and Adults: Their Social Perspectives and Culture, Selected Proceedings of the Fifth World Conference on Gifted and Talented Children, Greenhills 3113, Metro Manila, Philippines, August, 1983.
27. Voyat, Gilbert. "In Tribute to Piaget: A Look at His Scientific Impact on the United States." The Roots of American Psychology: Historical Influence and Implications for the Future. New York: The New York Academy of Sciences, 1977, pp. 342-349.

FIGURE 1
MODEL FOR INTELLECTUAL PRODUCTIVITY

INTELLECTUAL
PRODUCTIVITY (f) ((A) (B) (C) (D) (E))F)...
(AB))BC)...h)

KEY FACTORS	ESTIMATED VARIANCE
	CONTRIBUTION
A= ABILITY TO MASTER ABSTRACT SYSTEMS	(30-50%)
B= OPPORTUNITIES FOR TALENT DEVELOPMENT	(10-20%)
C= PARENTAL ENCOURAGEMENT OF TALENT	(10-15%)
D= SELF-CONFIDENCE IN ENVIRONMENTAL UNDERSTANDING AND MASTERY	(10-15%)
E= SUBCULTURE APPROVAL OF INTELLECTUAL ACTIVITIES	(5-10%)
F= PEER INFLUENCES	(5-10%)
AB, BC	
ETC. = INTERACTION OF KEY FACTORS	(15-25%)

Note: From J. J. Gallagher, 1983, August, The conservation of intellectual resources, Presidential Address presented at the Sixth World Conference on the Gifted and Talented, Hamburg, West Germany.

PREFACE

The computer's aiding in the identification of and providing a vehicle for the special interests and abilities of gifted and talented children is being explored in this project, "The Computer in Creative Mathematics." Utilizing a non-traditional learning environment, a "language" designed to be used within that environment, and students chosen from regular computer science classes, we are attempting to provide such a vehicle.

We are presently completing the third year of a five year study of this exciting concept. This is only a synopsis of a much longer paper. The complete paper can be obtained by contacting:

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THE VEHICLE

It is no easy task in many high schools to offer students an alternative to the traditional course content for ten weeks, to provide them with computers and materials to explore in a conducive learning environment for 43 minutes each day, and to obtain administrative support for such a project.

Fortunately, we have designed a computer science course in which the emphasis is on learning computer science and not a specific language. Thus, for the first three ten week quarters the students study the BASIC language. For the last ten weeks of the course the students can choose any phase of computer science and do an

in-depth study of that area. This fourth quarter provides the ten weeks needed for our project.

Oneonta Senior High School was one of the original 77 schools in the nation chosen by IBM to receive 15 PC's and all the software, including LOGO, in a pilot program to introduce the IBM computer into the educational setting. We chose to house these computers in a special lab available to all students during the day and not tied up by class instruction. This lab provided an effective setting for the project.

The next step in getting the project off the ground was to gain administrative approval and support. Understandably, the key question asked by the administration was, "In what ways will our students benefit from this project?" It was explained that they would benefit in two significant ways. First, students would learn how to operate and become familiar with a different computer, since their first three quarters of study involved using TRS-80 computers. Second, and more importantly, they would be learning a new computer "language" through graphics, an area we did not teach in the computer classes. The administration approved the project in 1985 and has continued to be supportive.

SELECTION OF STUDENTS

Since the object of this project was to provide a special "liberating" learning environment and an avenue through which the students could leave "the beaten paths", a major concern for us was the selection of students who would, when provided with this liberating environment, maximize the opportunity. This required a careful selection of self-directed, capable students who could work with a minimum of direction. During the first year of the

project the selection process was aided by having a pool of 120 students in six computer science classes. There was a list of fourteen juniors and seniors who had completed three years of high school mathematics, had taken one semester of pre-calculus, and were presently taking calculus.

In the second year, however, the pool of students was only 40 students in two computer science classes. My colleague, Dr. Coutant, and I thought we might try to utilize some younger students and perhaps have them continue in the project independently in future years. Thus, in the second year, we included some sophomores, advanced students who were completing their third year of high school mathematics and planning to take pre-calculus in their junior year.

In the third year of the project we were down to a pool of only 20 students from one computer class. We once again chose juniors and seniors who met the same criteria used in the first year of the project.

After establishing the criteria for selection, I conferred with Mrs. Jacqueline Scavo, Coordinator of computer science, and also the mathematics teacher who taught geometry to most of the selected students. We felt that the students' response to geometry gave us a keen insight into their ability to conceptualize. Mrs. Scavo helped me in making the final selection of students whom I then invited to participate in the project.

Approaching the students was a very critical step. I wanted to give them enough information to whet their appetites, but I did not want them to be familiar with the whole project until they were well into it for fear that I might influence their thinking, approach, and direction. I

explained that I wanted to include them in a special project. In this project they would be required to learn a new computer "language" (LOGO) and to use the IBM computers. I noted that they would be on their own, using the LOGO "language" to pursue any area of interest dealing with computers. Initially we stated that the area should pertain to mathematics or calculus, but after the first year revised that to be any area. I explained that their learning would be mostly self-directed study, but I would be available for assistance when needed. Each student was approached individually and was asked to let me know in a week. Most students were enthusiastic about the project.

STUDENTS' CHARGE

I handed the students a copy of IBM LOGO: Programming with Turtle Graphics and said, "Learn LOGO through graphics." As they learned the graphics, which they had not been exposed to prior to this time, I asked them to consider: 1) possible mathematical projects or problems 2) any possible project that might be interesting to them and that they might want to pursue in some depth later on in the quarter. In order to assist the students in their daily work and to keep a record of their progress, thoughts, feelings, accomplishments, and disappointments, they were asked to keep a daily log. They also kept a diskette of all their programs, those copied from the book, those altered by the student and those totally created by the student. The last student requirement was a final exam, a copy of which is attached. The purpose of this final exam was to encourage students to examine how they think and to provide a vehicle through which they could draw their own conclusions about this total project. The logs, diskettes and final exams provided us with the basis for evaluation of the students' progress and the basis for evaluation of the total project.

At this point I would like to clarify Dr. Coutant's reference to my teaching the students list processing, recursion, graphics etc.. As the previously stated instructions indicate, I did not sit the students down in the classroom and discuss these topics. Instead, through the use of LOGO and turtle graphics, these topics were "learned".

EVALUATION

We have structured the results of this ongoing project to follow the criteria for evaluation as discussed previously by Dr. Coutant. The seven girls and fourteen boys chosen for this project ranged in ages from fifteen to eighteen. They worked from twenty-four to thirty-four days for forty-three minutes each day.

On the first day of the project the students were administered the Longeout Test. The results were predictable since these students were all well beyond this stage in their thought process. Out of twenty eight questions, twelve were testing concrete thinking. Of these twelve, one question was missed only once. Of the sixteen questions testing formal thinking, the average was thirteen correct and the range was from eleven to sixteen correct. Thus, according to the test results, each individual in the group tested well in formal operational thinking. Most students felt that the test was very easy.

LEARNED IBM

In evaluating whether the students have learned to use the IBM computer, I must conclude from the lack of comments in their logs and from the volume of work that was produced by each individual on the computer, they all learned how

to use the IBM PC Computer specifically with the software "language" LOGO.

LEARNED LOGO

Prior to begining this project, all of the selected students had demonstrated a high degree of understanding of BASIC. However, as I have stated, they did not have any understanding of graphics. By the conclusion of this project, all of the students have gained a thorough knowledge of LOGO Graphics and varying degrees of knowledge of LOGO as a very powerful language. Their knowledge of graphics was demonstrated on their diskettes and in their logs as they worked through the graphics book changing and adapting the programs already supplied in the book and creating their own programs, utilizing the concepts encountered in the book.

Throughout the students' logs there is much evidence of affective as well as cognitive learning. Many students have commented about and expressed a variety of emotional involvement. Through this project we have observed a positive affective tone created by the "language" of LOGO, the computer, and the conditions for learning. It continues to be a source of great pleasure for us to see the way high school students become completely absorbed in learning with the computer. We have noted how the students have become emotionally involved and express this emotion quite freely.

The students' learning of LOGO as more than just graphics took on a different approach. Since the graphics were totally new to them, they had no frame of reference to compare it with. However, LOGO as a computer language was constantly being compared to the languages they had learned previously. Different sturctures that existed in other

languages were looked for in LOGO. Initial impressions of the language of LOGO were sometimes proved correct and sometimes proved incorrect. Many of the students were able to understand and describe the power of LOGO as more than just a graphics "language".

The students' logs gave us a feeling for the diversity of approaches they used in learning LOGO and LOGO graphics. Each student relied on his/her own thoughts and ideas rather than being directed or "taught how to" in the traditional sense. The graphics book provided the needed structure for most of the students to advance, but did not hinder their own exploring and diverging from the given samples.

MATHEMATIZE

Although the concept of "mathematize" is hard to evaluate, there were definite glimpses in the students' logs of them "grasping the whole situation as opposed to calculating the parts". One concept of mathematize is the ability to solve problems. By having the students go through the learning on their own, they created their own problems and also demonstrated good problem solving techniques to solve these problems. One student used the concept of problem solving working backwards. A number of students refer to the concept of a top down design in approaching their programs. Other students have indicated that the editing process in LOGO has made them more aware of paying attention to details.

OWN THINKING PROCESS

The information gathered about the students' thinking process was mostly in response to question two in the students' final examination. Responses ranged from waking

in the middle of the night with the answer to a problem, not being able to write thoughts down quickly, to one student stating he had no thinking process at all! A few related their thought process to already learned skills.

SKILL FOR COPING

There seem to be as many ways of coping as there are subjects for this project. Some students use previous knowledge to cope with inadequacies of the language. Other students have coped by not straying from the graphics book and the reference book provided for the students' use. They feel that they must proceed page by page to understand the language fully before they branch out into some project. A number of students felt that they had to write their work out on paper to deal with the frustrations that kept rising out of the self-directed learning. Backing away from the immediate situation and letting the subconscious work on the problem was a method utilized by others. At least two students felt that their previous knowledge hindered their ability to let ideas and concepts flow freely in their minds.

NEW IDEAS

Although some students commented on how ideas came to them, I feel certain that since the students were unskilled in analyzing their own thought processes and untrained in writing logs, many of the new ideas that did occur were not recorded. At least one-fourth of the students commented in their logs about how the lack of specific directions and the total freedom were idea stifling. Over half of them felt that ten weeks was not enough time to complete their projects. They felt if they had more time they could give a better evaluation of the total process.

ADDED TO DATA BASE

At this point, the concept of the students' exploring their own ideas without interference has been well established. We did not, however, want the students to work in a vacuum. Dr. Coutant explained that the students would get together once a week and share their ideas, suggestions and problems. Unfortunately, we were not able to keep to the strict once a week get together, but when the students did get together, there was much sharing. By sharing, they were able to relate parts of the data base to each other. The students, especially in the last two years, did not wait for the weekly get togethers to share ideas. Many of them were working on the project at the same time and could easily share ideas. At least one student invited another non project member into the IBM room and taught her how to use the newly learned commands.

SMALL DISCOVERIES

Many of the students "discovered" what we would consider small discoveries. Discovering about the keyboard of the IBM computer, creating new commands in LOGO to find out later on that they exist in the reference book, having a graph of an equation skip over "holes" in the graph or skip over asymptotes and deriving the quadratic equation while working to solve a quadratic are a few of the small discoveries these students have been able to express. Because the students have all learned LOGO graphics and varying degrees of the LOGO "language" during this project, all the facts they have discovered would be too numerous to mention.

CONCLUSION

The first three years of this project have been successful in creating a liberating learning environment for the students. They have explored, created, and learned without a curriculum. The computer, the LOGO "language", and the students' curiosity provided enough motivation for most of them to progress at a rate beyond our expectations.

We have learned, however, maturity should be a criterion in student selection. Throughout this project we have had some very mature young people who are self-motivated and appreciate the opportunity to learn for learning's sake. We have also seen that the immaturity of some students has thwarted their progress. In the next two years, because of the freedom extended to each student, the maturity factor will play a role in our selection of students.

FINAL EXAM LOGO

PLEASE NOTE: As you respond to each of the following, it is essential that you refer to your log for supporting examples and specific details.

1. A. Identify clearly your objectives for this project.
B. How did you structure your project to achieve these objectives?
2. Select either A or B. Through specific references to your project, write several sentences supporting that opinion.
 - A. My project heightened my awareness of my thinking process.
 - B. My project did not heighten my awareness of my thinking process.
3. As you worked through your project, how did you develop "new ideas?" Be sure to express yourself carefully and clearly to convey the style/process you used.
4. Describe "small discoveries"(ideas, lines of thought and/or facts you had not been aware of before) that you made through the project.
5. In your opinion, what is one negative aspect of LOGO? If you could, how would you change this aspect to improve the language?

BIBLIOGRAPHY

- Bak, Mikkie. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Buzzy, Brett. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1986. Dates 4/24/86-6/18/86.
- Dromey, R.G. How to Solve It by Computer. Englewood Cliffs: Prentice Hall, 1982.
- Fleisher, Sarah. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Gardner, Martin. Aha! Insight. New York City: Scientific American, Inc., 1978.
- Grant, Russell. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1986. Dates 4/24/86-6/18/86.
- Heyn, Todd. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1987. Dates 4/7/87-6/9/87.
- Hoffman, Clifford. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1986. Dates 4/24/86-6/18/86.
- Hollist, Joseph. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1987. Dates 4/7/87-6/9/87.
- Kreger, Lori. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Lare, Katrina. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Lester, Christopher. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1986. Dates 4/24/86-6/18/86.
- LOGO. Boca Raton: LOGO Computer Systems, Inc., 1983.
- LOGO: Programming with Turtle Graphics. Boca Raton: LOGO Computer Systems Inc., 1983.
- Miller, Ted. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1986. Dates 4/24/86-6/18/86.
- Moulton, Jeanne. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Moskos, Kristine. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1986. Dates 4/24/86-6/18/86.

- Papert, Seymour. Mindstorms: Children, Computers, and Powerful Ideas. New York City: Basic Books, Inc., 1980.
- Pence, Heather. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Polya, G. How to Solve It. Garden City: Doubleday and Company, 1957.
- Romero, Vicky. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Russell, David. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1987. Dates 4/7/87-6/9/87.
- Sexton, Andrew. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1987. Dates 4/7/87-6/9/87.
- Theologes, Terry. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1986. Dates 4/26/86-6/18/86.
- Ventre, Donald. LOGO Log and Final. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.
- Xanthaky, Peter. LOGO Log. Oneonta: Oneonta Senior High School, 1985. Dates 4/23/85-6/20/85.

RE-ENERGIZING THE SCHOOL MATHEMATICS CURRICULUM

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I. TRENDS IN SCHOOL MATHEMATICS SINCE SPUTNIK

Beginning with Sputnik in 1957, the School Mathematics scene has been more or less in flux. The late 50's and early 60's were dominated by "the new math" movement. This was followed by the increasing realization that the revision of content alone, especially if it was more formal and symbolic and not particularly well understood or accepted by teachers in the classroom, was not enough. Discovery learning in the USA and activity learning in the UK formed the next wave in the mid to late 60's - a trend which was generally welcomed but which subsided gradually due to a combination to economic cutbacks and public perceptions that the bread and butter basics of computation and arithmetic were being neglected. Thus, a new thrust became apparent in the 70's, the back to basics movement, with a concurrent emphasis on assessment and testing (Robitaille, 1980). A possible solution then began to evolve in the late 70's as the hand calculator emerged and relevance and applications became the focus of change. Finally, at the beginning of the 80's the landmark publications of an Agenda For Action (NCTM 1980) and the report of the Cockcroft Committee in the UK (1982) redefined a much more comprehensive context for rethinking school mathematics.

The NCTM agenda report made eight recommendations, the first three of which (paraphrased) were:

- i) problem solving must be the focus of school mathematics,
- ii) the concept of basic skills "must include those things which are essential to meaningful and productive citizenship for the immediate and future"
- iii) mathematics programs must take full advantage of the powers of calculators and computers at all grade levels.

The other recommendations were equally praiseworthy and related to higher standards, more flexible curricula, and higher levels of support systems for the school mathematics enterprise generally. The word "must" figured in all of the last five recommendations.

The Cockcroft inquiry into the teaching of mathematics in the UK began in September 1978 and the Committee submitted its final report in November 1981. Apart from meeting on 64 days which included three residential meetings, it commissioned studies of the mathematical needs of employment and of adult life generally and a review of existing research on the teaching and learning of mathematics. Finally, members made many visits to organizations and firms and numerous submissions were received.

The report is in three parts - the first considers the importance of mathematics as a discipline or school subject for the individual and society, the second examines mathematics in schools - its content, methods, assessment, intent. Part three discusses the context and resources for mathematics in schools in terms of facilities and, especially, mathematics teachers, including teacher-supply, qualifications, and inservice support in its discussions. While the report represents a very careful, thorough and comprehensive study of school mathematics it distributes its many recommendations throughout the report and only comments in a general way on them in a final chapter ('The Way Ahead').

The surveys and research studies commissioned by the Committee revealed that adults often had feelings of anxiety, helplessness, fear and even guilt when required to undertake a simple piece of mathematics. There was also perception that accuracy and speed showing all neat and working neatly and using all the proper methods to obtain exact answers were all central characteristics of learning mathematics. Specific areas which presented difficulties

were:

1. Understanding of percentages.
2. The meaning of rate of inflation.
3. The reading of charts and timetables.
4. Willingness to use the hand calculator and discouragement at the large number of figures after the decimal point.

The Committee recommended that teachers ensure that their pupils have the abilities:

"To read numbers and to count, to tell the time, to pay for purchases and to give change, to weigh and measure, to understand straight forward time tables and simple graphs and charts and to carry out any necessary calculations associated with these."

Additionally, students should develop a feeling for number which allows sensible estimation and approximations to be made and most importantly, adults must have sufficient confidence to make effective use of the mathematical knowledge they possess.

Roughly speaking, these abilities constitute what the report calls numeracy - the ability to appreciate and understand mathematics as a means of communication.

The report deals with computers in general terms pointing out that (in 1982) "we are still at a very early stage in the development of their use as an aid in teaching mathematics". It reminds its readers that mathematics teachers have so far not made great progress in the use of other aids such as the overhead projector or the calculator. Specific mention is made of the need to produce software programs which are not just "extra's" but which can contribute to the mainstream mathematical work of the school.

Finally, the report argues strongly for a higher than average level of support for mathematics teachers already serving in schools, claiming that school-based inservice support is of fundamental importance but needs to be

supplemented by courses on a local or regional basis. In this context, the leadership of mathematics coordinators or heads of departments is seen as essential and it is implied that these people must receive adequate support and training. Additional financial support for these purposes is necessary if improved mathematical education is to result. In order for all the issues and recommendations to be addressed, since the committee believes that the teaching of mathematics must be addressed as a whole, it places the responsibility for bringing about the necessary changes on six agencies supported by the public at large. The six agencies are: teachers, local education authorities, examination boards, central government, training institutions and those who fund and carry out curriculum development and educational research.

Since 1982 there have been many developments from both sides of the Atlantic including reports by various committees and commissions as well as continuing debates at conferences and in journals and the emergence of various experiments and projects directed at specific aspects of mathematics education. Among these are the ITMA project at Nottingham University, (Burkhardt, 1983; Fraser, 1983; ITMA 1985), the PRIME project at Homerton College, Cambridge (Shuard, 1986; SCDC, 1986), the work of Seymour Papert and others at MIT (Papert, 1979; Weir, 1987) and the University of Chicago Secondary Mathematics Project (Usiskin, 1985; UCSMP, 1985).

II. PRIORITIES IN CONTENT AND EMPHASIS

1. Work by the Author since 1979.

After a reduction in activity as a full time professional mathematics educator due teaching responsibilities in other areas of education, the author began a rethinking of the needs of mathematics education in 1979. His first step was to undertake a study of basic skills in mathematics by comparing assessment studies in the

UK, Canada and the US (Crawford 1980). This indicated the need to him to focus on estimation and approximation as fundamental areas of knowledge and skill needed by everyone in adult life, and a research study on this theme was completed in 1982 (Crawford 1982). During this study, he became even more convinced that this area should be used as a major bridge between mathematics, science and technology in schools. This led him to the hypothesis that much of the trouble with school mathematics (and perhaps science as well) was due to lack of emphasis on and understanding of the significance of measurement in the development of industrial and technological societies. As a consequence, he began to study the use of mathematics in high technology industries as a way of providing evidence on the actual uses of mathematics and hence the possibility of a shift in school mathematics from a heavy dependence on the needs and demands of university mathematics. Two outcomes were a research study of the mathematics used at a large telecommunications plant in Ontario (Crawford, 1984d, 1987b) and a paper delivered to the Third International Symposium on World Trends in Science and Technological Education (Crawford, 1984c). Additionally, a sabbatical leave in 1984-1985 was devoted to studying science and technology education with a view to linking them more closely with mathematics education in schools (Crawford, 1984c; 1985a). The impact of the computer was also studied and its likely effects reported in several papers (Crawford, 1984a, 1984f, 1985b). More recently, a focal point was reached in a first attempt to articulate a redesign of the mathematics curriculum in school (Crawford, 1986b).

2. Estimation, Measurement and Responsible Citizenship.

How do most, say 80%, of people use mathematics in real life? According to the Cockcroft report studies, and this is supported if one questions any sample of adults, they use it to estimate, to measure, and to make calculations mainly

involving percentages and decimals. They are doing this in an ever increasingly complex society. Measuring and controlling technologically based production by sophisticated measuring devices and mathematical techniques lie at the heart of wealth creation and technological advance. For example, an article in the magazine High Technology of July 1987 on super conducting illustrates this point well. In providing large superconducting magnets which consist essentially of a cable wound around a copper tube secured by suitably designed collars, it is stated that

"The cable must be kept from moving in response to the huge magnetic force it will experience. A shift of just one thousandth of an inch would generate enough energy to heat the wire above its particular temperature changing it abruptly from a superconductor to a state of ordinary electrical resistance. Following this transmission called a quench, the electric current would quickly heat the magnet to several hundred degrees and the entire SSCC would have to be shut down" (p.15).

And again, superconducting elements called Josephson Junctions are being used in an oscilloscope to measure signals as brief as ten pico seconds (10^{-11} sec.).

Thus a well-designed sequence of curricular experiences focussing on the ideas of estimation, accuracy and error of measurement followed by gradual introduction later to acceptable ranges of error and quality control in production has the potential to help today and tomorrow's students understand the significance of mathematics in an increasingly technological world.

At the same time, the interactions of our technological wealth-producing activities with the environment in which we live, are producing many undesirable side effects such as acid rain. We are therefore in great need of understanding the problems we are creating, so that we can learn to conserve and use the ecological system of which we are a

part, wisely, intelligently and prudently. It is therefore increasingly important for the ordinary citizen to have a better understanding of the use of precious natural and non-renewable resources such as air, water and energy fuels and sources (Allen, 1982; Crawford, 1987; Fremont, 1979; Peccei, 1982). Inevitably the questions of the distribution and sharing of wealth are becoming more pressing as evidenced by international disputes over oil, lumber, fishery and agriculture policies-all occurring in the context of a highly fragile international financial system. Hence as part of the curriculum of the 1990's there must be priority emphasis on the quantitative, logical, humanitarian and ethical aspects of these dilemmas - in a word, emphasis on mathematics for responsible citizenship.

3. Qualitative and Higher Order Thinking in Mathematics.

These same technologies which are crowding in upon the workplace need themselves to be understood and can help us greatly educationally. The computer as a means of calculation, information and as an expert helper, now requires that we rethink much of the curriculum, in our case the mathematics curriculum.

With the increasing realization that much tedious calculation and computation both in arithmetic and in algebra can be done by these machines, time is apparently released for teachers to focus on higher order thinking and learning. Two questions now come to the fore:

- i) What should be done with the released time?
- ii) Will students use calculators and computers intelligently or will they simply apply procedures which they think or assume to be correct without understanding or checking?

It seems clear that the solution is to put greater emphasis on understanding relevant ideas and contexts. And so the translation from concrete three dimensional reality via meaningful visual images to an effective and efficient

use of symbolic systems becomes ever more important. For example, in a series of researches by Hughes and others in Scotland (1983) and by Behr and others in the United States of America (1980), cited in Hughes (1986), children of ages 5-11 have been shown to have severe problems when asked to translate between different representations of arithmetic - either from concrete to written or from written to concrete. In particular, they have little pre-school experience of the symbols +, -, ×, and show great reluctance even to use these in relevant situations. Hughes makes a number of suggestions for a new approach to the learning of mathematics based on his research, among which are included several focusing on the child as learner (discover the learner's mathematical background, build on the learner's own strategies, respect the learner's invented symbolisms). In a final passage, he warns of the need to see the use of new mathematical tools and techniques in perspective.

"We want to introduce children to the tools and techniques which form part of our culture and which we believe will help them solve the problems facing them. Yet, as these techniques grow more powerful, there is a danger that they will become less accessible to young children and that teaching mathematics - already an immensely difficult task - will become even more demanding and time-consuming. Unless more resources are made available within the education system, pressure of circumstances will continue to make it exceedingly difficult for teachers to give new ideas, however important, the time and attention they deserve."

"If we can redesign our educational environments.... so that, instead of nullifying and ignoring young children's strengths, we are able to bring them into play and build on them, then I am confident that we will be able to meet the challenge currently facing us." (Hughes, pp 183, 184)

Skemp (1971,1976,1979) has become very well-known, particularly in recent years, for his work on schemas and reflective learning. His ideas of instrumental and relational learning have led to much discussion. Some years ago Skemp made a further interesting contribution to this area of transition from concrete to symbolic understanding (Skemp, 1982). Any communication, verbal, written or otherwise first goes into a symbol system. How this is interpreted, however, depends on what relationships are formed within the conceptual structure (e.g. 572 is usually interpreted as one number, not three single-digit numbers as it could be if it were a telephone area code). Skemp makes five suggestions for developing symbolic understanding, defining this term as:

"a mutual assimilation between a symbol system and a conceptual structure, dominated by the conceptual structure." (p.61)

Two of these suggestions are to stay with spoken language much longer and to use transitional informal notation as a bridge.

More recently, as part of the thinking emerging as a result of the Cockcroft report, Brissenden (1985) has focussed on developing mathematical discussion among pupils. He argues that talk is a way of developing and/or improving understanding, language skills, and social skills, and that it can also provide the teacher with continued detailed assessment of children's understanding and progress. Three aspects of the teacher's role are necessary:

1. choosing mathematical situations which support discussion effectively;
2. preparing lesson patterns and class organisations which afford proper opportunities for discussion;
3. controlling the two forms of interaction mentioned by Cockcroft that discussion is generated and sustained.

The reader is referred to Brissenden's account for further details but essentially the teacher must produce a well thought out mathematical situation and retreat to a procedural role which requires the teacher to exercise various skills "more or less sub-consciously and in time as a matter of habit".

The work of Hughes, Behr, Skemp and Brissenden all illustrate what I call qualitative mathematics. This is a term I inherited many years ago from Caleb Gattegno and have tried to explain in a paper given in Melbourne, Australia (Crawford 1984e). Briefly, it means spending much more of the available time in the mathematics class on basic ideas and relationships, and clarifying their meanings conceptually and qualitatively before enshrining them in what may well otherwise become meaningless procedures and formulae.

The recent ICMI report (Howson and Wilson, 1986) supports this position strongly.

"Certainly there is no place for compulsory mathematics taught as a set of rules and unexplained procedures. Education should be fundamentally rational, and in mathematics this implies that it should emphasise relationships between items of numerical and spatial knowledge. For example, the uses to which a particular geometrical shape can be put depends on the properties of that shape, and the various properties are not independent pieces of knowledge but are connected with each other. Again, in learning to handle number efficiently, it is as important to appreciate the connections between multiplication and division, and to recognise the situations in which they arise, as to be able to carry out the appropriate algorithms. This relational aspect of mathematics becomes increasingly significant as electronic devices become available to carry out routine procedures." (ICMI, 1986 p.28)

Finally, the authors of this ICMI report see many potential benefits of the computer in various content areas (calculus, probability and statistics, geometrical transformations) and in using spreadsheets, CAD packages, and simulations. However, they also envisage three key problems in using the micro for experimentation and investigation:

- (i) the preparation of teachers,
- (ii) the selection of suitable task situations,
- (iii) difficulties associated with knowing, consolidating and testing what the students have learned.

III. RE-THINKING THE SCHOOL MATHEMATICS ENTERPRISE.

1. Aims of School Mathematics

As part of the research study conducted by the author and reported in Crawford (1986a), a survey was made of the recent literature on aims and justifications for learning mathematics. Table 1 overleaf depicts the results of this survey. A number of perspectives can be seen. Cockcroft emphasizes mathematics being useful in adult life, especially as a precise communication tool while the Agenda focuses strongly on problem solving. A Canadian study of 1976 emphasizes the value of math as a language for communicating ideas, and more interestingly perhaps, as a cultural resource. The ICMI report already cited, while agreeing that school mathematics must "serve to equip students both to study other subjects and also to help with mathematical demands and problems they will meet out of school", emphasizes the affective components when it suggests that the curriculum should provide a foretaste of what mathematicians do, why they do it and of the pleasure the success solving of a mathematical problem can bring. Additionally, these authors argue that students "must appreciate that with mathematical knowledge they acquire

TABLE 1
Aims and Justifications for Learning Mathematics

Crawford and Others 1976	Taylor, Tarmadon Prescott 1971	Gardner, Glenn, Renton 1973	Coleman and Edwards 1976
Total of 33 objectives obtained by brain-storming grouped into 5 categories below: 1. Basic Math Abilities 2. Basic Applied Skills 3. Higher Math Abilities 4. Appreciation of Mathematics 5. Personal Work Habits	1. a language-vehicle for thought 2. enables precise descriptions and modelling 3. best vehicle for comprehending pattern 4. intellectual and aesthetic appeal and fascination of deep structural problems	1. for living and responsible adulthood (functioning adequately as a member of society) 2. for livelihood/vocation 3. mode of knowledge and experience involving concepts of a general abstract kind (education) 4. significant part of aesthetic, affective aspects of human endeavour	1. understand what mathematics is and what it is not 2. mathematics is a way of thinking 3. mathematics is a cultural resource 4. mathematics is an essential language for communicating ideas
Dienes 1978	Agenda for Action 1980	Cockcroft 1982	Maths 5-16 1985
1. learn to abstract - strip off irrelevances 2. learn to generalize 3. learn to formulate and cope with precision and precise messages 4. learn to work together 5. learn to respect opinions/values of others	1. problem-solving as major focus of curriculum 2. basic skills to be extended e.g. include estimating and approximating; Use in predicting; computer literacy 3. emphasize applications, and appropriate skills and strategies e.g. formulating key questions; discovering patterns and similarities 4. integrate use of calculator and computer into curriculum 5. create classroom environments for problem-solving 6. emphasize communication skills and clarity	1. maths is useful since it provides a powerful, concise, unambiguous means of communication. 2. enables development of mathematical skills and understanding required for adult life, for employment and for further study and training - 3. and for study of other subjects 4. helps develop appreciation and enjoyment of mathematics itself.	set of 10 aims further divided into five categories of objectives. 1. essential element of communication 2. powerful tool 3. study of relationships 4. fascination of intrinsic appeal 5. a creative process/activity allowing use of imagination and flexibility. 6,7,8. enables systematic independent cooperative ways of working. 9. encourages in-depth study 10. gain confidence in doing math.

desirable power".

Another dimension which now appears frequently in the literature on aims is that of the personal and developmental by-products of maths learning. For example, Dienes stresses learning to work with others and to respect their values and opinions. So does Maths 5-16 (the 1985 Department of Education and Science Publication in England). Finally, in a number of the sets listed in Table I, various other affective and aesthetic benefits are noted.

A useful synthesis of many of these aims has been given by Shirley Hill, in her summary of the recent symposium International Comparisons of Mathematics Education: Policy Implications for the U.S.A. (Hill, 1987). As Lesson #3 from the Symposium, she states:

"Our goals in mathematics education must include three primary facets:

- (a) improved mastery of those portions of mathematics which are basic and will remain basic;
- (b) more time devoted to higher order thinking skills which will be needed by a much larger fraction of our population in the future;
- (c) cultivation of student appreciation and experience with mathematics as a living subject, presented in the context of its profound applications to the world around us. (Hill, p.1)

An interesting attempt has been made by Cain and others (1985) to codify and assign priorities to the major goals which they consider appropriate for different ability level students in secondary school mathematics, and hence to structure emphases on different aims to fit different types and intelligence levels.

Finally, the recent ICMI report has wrestled with this general problem of aims and how school mathematics, school experiences can reflect their variety in a "reasonable" way for all pupils (op.cit.Ch.3). Howson and Wilson discuss

content and process, the relating of mathematics to other aspects of experience, and the pros and cons of compulsory and differentiated curricula. However, their purpose is not to come to any firm conclusions but rather to suggest alternatives for further debate and discussion.

Related areas on which much recent research and discussion have focussed are problem-solving (Schoenfeld, 1985; Brown, 1985) process activities (Bell, 1978; Romberg, 1983; Crawford, 1984d) different kinds of knowing (Noddings, 1985) and metacognition (Garofalo and Lester, 1985). All of these aspects of learning need continued study and attention, but cannot be described at length in the present paper.

2. Some Bases For Redesign.

Clearly, whatever set of experiences and how differentiated they are will depend greatly on the value system and cultural climate of the country or region in which the experiences take place, i.e. there is no universal answer. However, there are in my view (and this is supported by the work of Wilson who studied four widely differing geographical regions) some basic agreements which can be used to change school mathematical experiences to become more relevant in an age of information technology at least in developed countries such as the USA, the UK or Canada. Some of these have already been outlined in Crawford (1986b) and summarized in Crawford (1987a). Here, they are repeated in much the same form as the basis for rethinking the whole mathematics enterprise particularly at the secondary level.

BASIS I.

MATHEMATICS IS ESSENTIALLY A TOOL FOR SOLVING PROBLEMS

This has been true throughout history and is the essential reason for studying and creating mathematics.

Although we now think of mathematics as the study of axiomatic systems and structures, these mental artifacts only become of value in the real world when they are applied to solve real problems. For the ordinary individual, the basic uses of mathematics are the same as ever - estimating, measuring, costing, designing and solving personal or societal problems.

Basis II

THE CONTEXT IN WHICH MATHEMATICS IS LEARNED MUST PROVIDE SCOPE FOR A FLEXIBLE MIXTURE OF ACTION AND REFLECTION IN SOLVING MEANINGFUL, RELEVANT PROBLEMS BOTH INDIVIDUALLY AND COOPERATIVELY.

Rote learning and lack of opportunity to understand ideas via the use of manipulative or visual materials must be minimized and other aspects of qualitative mathematics such as non-threatening discussion, group work, practical and applied problem-solving and project involvement must be introduced increasingly so that learning becomes natural, well-motivated and meaningful. These two bases then lead straightforwardly to two major goals.

- 1) Students learn to become better problem solvers.
- 2) Students learn to become increasingly independent learners. Mechanisms and methods or strategies for achieving these goals must include
 - i) The central involvement of the students individually and co-operatively in their learning, using methods which produce interest, enjoyment and commitment to effort in learning.
 - ii) Gradual withdrawal of the teacher as the prime mover and resource for learning.
 - iii) A particular focus on the concepts and activities of designing, making and creating real or intellectual objects which are of mathematical

significance and yet intrinsic value and personal satisfaction for the individual.

As long ago as 1957, Sawyer and Srawley wrote an excellent book called *Designing and Making* which proposed exactly these ideas

"Children often ask, 'Why do we have to learn arithmetic?' There are various answers--'You need it to go shopping', and so forth. The weakness of these is that they appeal to the reason alone while the question is not really a request for information. It really means 'I find this dull', and the only effective answer is one directed to the feelings. The best answer of all is one not of words but of action--to let the child embark on some activity that is unquestionably exciting, and to let it discover at some stage that its progress is held up by lack of mathematical knowledge."

"The more the children learn to organize their own lives, the more efficient the education will be. Things can go ahead without the help of the teacher."

4. Current, new and emerging technologies such as the micro-computer should be used intelligently to support these goals and the mechanisms which have been outlined - in particular the computer should be used to simulate things done by humans. The visual and interactive potential of the computer for learning are its two most important characteristics which need to be understood fully and harnessed appropriately for high quality learning.

IV. IMPLEMENTING A RE-ENERGIZED CURRICULUM.

Assuming the validity of this analysis and refocusing of the mathematics curriculum - how is it to be realized?

To achieve it, in this author's view, requires attitudinal and knowledge changes in teachers, administrators, politicians and probably the general public as well. Attitudes tend to be changed only if something is

shown to be an improvement on established practice or possibly because sheer necessity requires something new to be tried. The first approach is voluntary, the second involuntary.

1. School and Curricular Reform.

Goodlad (1983) claims that in his major research study of schooling in the USA (published in 1984), two major curricular deficiencies stand out. They are

- i) a failure to differentiate and see the relationships between facts and the more important concepts facts help us to understand and
- ii) a similar failure to see subjects and subject matter as mechanisms for the real goal of personal development.

Part of the overall failure also stems from the fact that schools are not the only educational agency.

If we seriously believe in the possibility of achieving to some extent the lofty goals some jurisdictions are now setting (e.g. Ontario, 1984), then in this age of information technology we must respond to change by creating a self-renewing school. According to Heckman, Oakes, and Sirotnik (1983), what is essential is

"A school staff that constantly works together to examine the school's condition, identifies problems, and develops alternatives based on all forms of knowledge. The self-renewing school may use ideas from the outside, but the intention is not to make the school a better target for innovations developed outside the school."

(Educ. Leadership, April 1983 p.29)

Joyce and others (1983) examine this theme in detail, using as a strategy the development of what they call Responsible Parties-local administrators, teachers and community members who examine the health of their school

continuously, select targets for improvement, and draw on knowledge about school improvement to implement desired changes." They identify three stages of school improvement, which are shown in Figure 1 below. (op.cit., p.7)

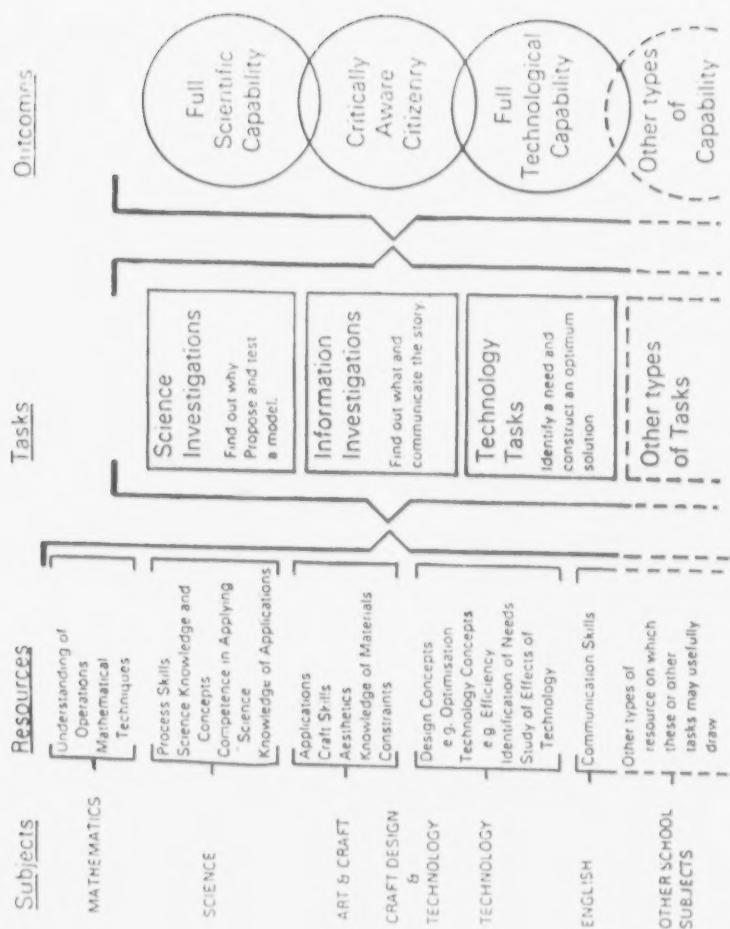
Three Stages of School Improvement

	Scope	Tasks
STAGE 1 Refine:	Initiate the process	Organize Responsible Parties Use effectiveness criteria Improve social climate of education
STAGE 2 Renovate:	Establish the process	Expand scope of improvement Embed staff development Improve curriculum areas
STAGE 3 Redesign:	Expand the process	Examine mission of school Study technologies Scrutinize organizational structure Develop long-term plan

According to this scheme, re-energizing school mathematics cannot occur without the conscious organizing of a "reforming" group, which clarifies goals and standards and develops effectiveness criteria relating to the desired change.

2. A Promising Model of Curriculum.

One model of curriculum which seems to have great potential in moving the mathematics curriculum towards the goals of problem-solving, personal and social development and independent learning is the Resources/Tasks Curriculum Model proposed in the U.K. by Black and Harrison (1985). This model has its origin in the technology and science area of the curriculum but appears to be generalisable across the



A CURRICULUM OF RESOURCES AND TASKS
(extracted from Black and Harrison P. 26)

FIGURE 2

curriculum and in fact will only work properly if this occurs.

Figure 2 summarises the model in diagrammatic form. Briefly, subject areas are seen as resources, which can be applied appropriately to tasks. Thus teachers have two aspects to their role. They are specialists when they are teaching their subject area as a discipline but are members of a resource team when students are engaged in cross-disciplinary or ultra-disciplinary tasks or projects. Among the advantages of this model are its flexibility in time allocation and organization, its wedding of theory and practice and its subordination of subjects to become means not ends in themselves. Also the focus on tasks in projects allows for much greater emphasis on worthwhile, meaningful activities chosen to be interesting and satisfying to students. The concepts of designing, making and creating can be brought in centrally as features of such tasks and hence motivate students strongly provided the whole system is carefully and wisely thought out.

3. The Teacher, Inservice Education and Integrated Learning.

In his international study of cultural contexts of Science and Mathematics Education, Bryan Wilson (1981) reports a growing realization that the teacher is the single most important factor in effective curriculum development, and that curriculum reform needs to be integrated with teacher education. Certainly, this is borne out in the area of mathematics education where numerous innovative projects, particularly The New Maths and more recently the Unified Science and Mathematics for Elementary Schools Project (USMES) failed largely because teachers were unwilling or unable to embrace the philosophy and commitment needed to implement the new project successfully (Howson, Keitel and Kirkpatrick, 1981). Some of the problems of change have been highlighted in the fascinating study of Inservice Education of Mathematics Teachers by Edith Biggs (1983).

Among her unexpected findings were these three:

1. the necessity for a new scheme in mathematics to be democratically prepared and tried out by all members of staff if it was to be wholeheartedly implemented;
2. the necessity for the principal to be actively involved in the project if lasting changes were to be made;
3. the necessity for the principal to have enough knowledge of mathematics; (Biggs p.193)

Howson, Keitel, and Kilpatrick identified five approaches to curriculum development in mathematics going from "the new Math" to "integrated teaching" and concluded that,

"The formative and integrated teaching approaches precipitated the formation of an innovatory strategy to replace the R-D-D model"...

"The new strategy aimed at strengthening the teacher, and at making him better able to function at a professional level and of assuming a creative role within the overall curricular approach. No longer was he to be regarded as the mere performer of a ready-to-use curriculum." (p. 128).

These authors argue that the problems inherent in making these 'improvements' in the teacher may be solved by supplying "paradigm" materials to act as ideas and starting points, but that these would have "no claim to universality".

More generally, recent international trends are all in this same direction - towards integrating learning, more inter-disciplinary work, and greater self-reliance in learning. Thus the 1979 Council of Europe document Innovation in Secondary Education in Europe distinguishes three major factors at work - new conditions of education, new developments in theories of education, and the growth of educational technologies.

"This situation makes new demands: today's pupil is not like his predecessor or his class-mates, he needs a different kind of teaching, more highly personalised and better adjusted to his own particular needs and his growing demand for independence and freedom." (ibid, p.48)

Haigh (1975) discusses the pros and cons of integration and concludes that there is a valid place for it but only if certain conditions are satisfied. A fuller discussion of these aspects can be found in Crawford (1986b).

V. TOWARDS RELEVANT AND REALISTIC SCHOOL MATHEMATICS.

So far, an outline has been given of some of the ingredients deemed either essential or desirable in order to arrive at interesting and worthwhile mathematical experiences for the great majority of students in their secondary schooling - roughly to age 16.

Briefly summarized, these are:

- i) focus on basic mathematical ideas and relationships which will be used frequently in adult life e.g. estimation, measurement, percentages, decimals;
- ii) emphasize using these to solve problems of individual and social significance;
- iii) blend work on mathematical ideas, processes and topics as an evolving system and structure with their application to real situations and problems;
- iv) increasingly emphasize independent learning and reliance by the student on his own resources for problem formulation, data gathering and problem solution;
- v) use the calculator and computer intelligently to reduce tedium, by having them perform routine calculations and operations and to create stimulating mathematical environments;

curriculum currently being pioneered at Quorn Community College, Leicestershire (Hewlett 1986).

VI. CONCLUSION.

No one single mathematics curriculum will ever emerge as "the correct one". Ideas and the realities in which they become embodied change as a given society and culture change. At the root of all change, are the cultural values which cause or resist that change. Hence, what is proposed here, is the summation of one individual professional and personal experiences, based on his value system as that too interacts with various cultural milieu. It is for the reader to assess how important these thoughts and proposals are for mathematics education in particular and more generally for improving schooling and education.

References

- Bell, A. (1978) "The Learning of Process Concepts of Mathematics" in Proceedings of 2nd International Conference for the Psychology of Mathematics Education, Osnabrueck, December 1978.
- Behr, M.; Erlanger, S. and Nichols, E. (1980). "How Children view the equals sign" Mathematics Teaching 92, 13-153.
- Biggs, E. (1983) Confident Mathematics Teaching 5-13. Windsor, England: National Foundation for Educational Research-Nelson.
- Black, P. and Harrison, G. (1985). In Place of Confusion - Technology and Science in the School Curriculum. London: Nuffield-Chelsea Curriculum Trust and the National Centre for School Technology, Nottingham.
- Brissenden, T. (1985). Rewriting the Mathematics Script: Discussion and Children's Language in Mathematics. University College, Swansea: Faculty of Education.
- Brown, S. I. (1985) "Problem-solving and Teacher Education: the humanism twist models and muddles" in Morris, R. (ed) Studies in Mathematics Education Vol 4. UNESCO, Paris.
- Burkhardt, H. (1986). "Computer Aware Curricula: Ideas and Realisations" in Howson, A.G. and Kahane, J.P. (Ed.). The Influence of Computers and Informatics on Mathematics and its Teaching. Report of the 1985 Strasbourg Conference.
- Burkhardt, H. (1983) "How may we move the Curriculum?" Paper based on a talk given in September 1983 to the British Society for the Psychology of Learning Mathematics.
- Cain, R. W., Carry, L. R. & Lamb, C. E. (1985). "Mathematics in Secondary Schools." In N.C.T.M. 1985 Yearbook (Chapter 2). Reston, VA: The Council.
- Christiansen, B., Howson, A.G., and Otte, M. (ed) (1986) Perspectives on Mathematics Education. (Papers submitted by members of the Bacomet group). Dordrecht, Holland: D. Reidel Publishing Co.
- Cockcroft, R. D. and Others (1982). Report of An Inquiry into the Teaching of Mathematics in Schools. London: H.M.S.O.
- Council of Europe (1979). Innovations in Secondary Education in Europe. Strasbourg: Council of Europe.
- Crawford, D.H. (1987a) "School Mathematics, Advanced Technologies and Responsible Citizenship", Paper to be presented at the 4th International Symposium on World Trends in Science and Technological Education, Kiel, West Germany. Aug. 1987
- Crawford, D.H. (1987b) "Approaching the School Mathematics Curriculum from an Advanced Technology Viewpoint: A Pilot Research Study and its Implications". A Paper given at the Annual Conference of the Canadian Society for the Study of Education, Hamilton, Ont. June 1987.
- Crawford, D. H. (1986a). The Mathematics Curriculum and the Use of Mathematical Knowledge and Skills in Canada in an Era of High Technology. Report to the Social Sciences and Humanities Research Council of Canada June 1986. Mimeo 35 pp. & App. 1 to 7. Kingston, Ontario: Queen's University.
- Crawford, D. H. (1986b). "Re-Designing School Mathematics for the Information Technology Age." A paper prepared for the Annual Conference of the Canadian Society for the Study of Education, Winnipeg, June 1986.
- Crawford, D. H. (1985a) "Education in an age of information technology: Initiatives, problems and possible solutions." Paper given at Research Seminar, Faculty of Education and Design, Brunel University, London.
- Crawford, D.H. (1985b). "The Logo Phenomenon - Some Personal Impressions and Questions: An Aid to Continuing Evaluation and Development". A Paper presented at the Logo and Mathematics Education Conference, University of London Institute of Education, March 1985.
- Crawford, D. H. (1984a). "The concepts of precision, accuracy and error in mathematical, science, and technological education." Proc. 3rd International Symposium on World Trends in Science and Technology Education, vol. I, Brisbane, Australia, Dec. 1984.
- Crawford, D. H. (1984b). "School mathematics and information technology: Issues and Implications." (Keynote address) Proc. 21st Annual Conference of the Mathematical Association of Victoria, Dec. 1984.

- Crawford, D. H. (1984c). "School mathematics in a wider perspective." Presentation to Faculty of Education Colloquium, Monash University, Melbourne, Australia, October 1984.
- Crawford, D. H. (1984d) "A Taxonomy of Process Abilities and Skills in Mathematics". Paper prepared in connection with a short communication at the 5th International Congress on Mathematical Education, Adelaide, Australia, August 1984.
- Crawford, D. H. (1984e) "Qualitative Mathematics - The First Priority", in Proc. PRE-ICME Satellite Conference, Research Council for Diagnostic and Prescriptive Mathematics, Melbourne, Australia, August 1984.
- Crawford, D. H. (1984f) "Using Technology in Technology and Learning - Some Thoughts for the 80s", in 1984 Research Monograph Research Council for Diagnostic and Prescriptive Mathematics.
- Crawford, D. H. (1982) "Estimation and Approximation - Results and Recommendations from Recent Research." Proceedings of the Fourth Annual Meeting of the North American Chapter of the Psychology of Mathematics Education, Athens, Georgia, October 1982.
- Crawford, D. H. (1980) "A Comparative Study of National and State/Provincial Assessments of Basic Mathematical Skills in U.S.A., Canada and the United Kingdom." Paper presented at the Annual Conference of the Can. Society for the Study of Education, Montreal, P.Q.
- Department of Education and Science (1985). Mathematics from 5 to 16, Curriculum Matters 3. London, England: Her Majesty's Stationery Office.
- Fraser, R. (1983) "Microcomputers and Teacher Education" Proceedings of 4th International Congress on Mathematical Education Berkeley, Cal. Boston: Birkhauser Inc.
- Fremont, H. (1979) Teaching Secondary Mathematics Through Applications, (2nd ed.) Boston, Mass: Prindle, Weber and Schmidt.
- Garofalo, J. & Lester, F. L. Jr. (1985). "Metacognition, cognitive monitoring and mathematical performance." Journal of Research in Mathematics Education, 16(3), pp. 163-176.
- Goodlad, J. I. (1984) A Place Called School: Prospects for the Future. New York: McGraw-Hill.
- Goodlad, J. I. (1983) "Improving Schooling in the 80s: Towards the Non-Replication of Non-Events". Educ. Leadership, Vol.40, No.7, 4-7. (Apr. 1983).
- Haigh, G. (1975). Integrate! Classroom Close-Ups I. London: Allen and Unwin.
- Heckman, P. E., Oakes, J. and Sirotnik, K. A. (1983) "Expanding the Concepts of School Renewal and Change" Educational Leadership 64, April 1983, 26-33.
- Heppenheimer, T. A. (1987) "Superconducting - The New Billion Dollar Business". High Technology, July 1987, 12-18.
- Hewlett, M. W. (1986) Curriculum to Serve Society: How Schools Can Work for People. Loughborough, Leics: Newstead Publishing Limited
- Hill, S. (1987) "International Comparisons Symposium's Summary." Proceedings of International Comparisons of Mathematics Education Symposium: Policy Implications for the USA, January 1987. Washington, USA: Mathematical Sciences Education Board.
- Hord, S. M. and others (1987) Taking Charge of Reform. Alexandria, Virginia: Association for Supervisors and Curriculum Development.
- Howson, A. G., & Kahane, J. P. (Eds) (1986) The Influence of Computers and Informatics on Mathematics and its Teaching. Cambridge, England: Cambridge University Press.
- Howson, G., Keitel, C., and Kilpatrick, J. (1981) Curriculum Development in Mathematics, Cambridge, England: Cambridge University Press
- Howson, G. and Wilson, B. (1986) School Mathematics in the 1990s ICMI Study Series. Cambridge, England: Cambridge University Press
- Hughes, M. (1986) Children and Number - Difficulties in Learning Mathematics Oxford: Basil Blackwell
- Hughes, M. (1983) "What is difficult about learning arithmetic?" In Donaldson, M., Greve, R. and Pratt, C. (Eds) Early Childhood: Development and Education. Oxford: Basil Blackwell
- Investigations on Teaching with Microcomputers as an Aid (I.T.M.A.) (1985). A catalogue of resources by members of the ITMA Collaboration and collaborating groups and individuals. Nottingham: Shell Center for Mathematics Education
- Jamieson, I. (ed.). (1985). Industry in Education: Developments and Case Studies. Harlow, England: Longman Group Ltd.
- Joyce, B. R., Hersh, R. H., and McKibbin, M. (1983) The Structure of School Improvement. New York: Longman.
- Morris, R. (ed) (1985) Studies in Mathematics Education Vol. 4. The education of secondary school teachers of mathematics. Paris: UNESCO.
- National Council of Teachers of Mathematics. (1980). An agenda for action: Recommendations for school mathematics for the 1980s. Reston, VA: The Council.
- National Council of Teachers of Mathematics. (1983). The agenda in action. National Council of Teachers of Mathematics 1983 Yearbook, Reston, VA: The Council.
- National Council of Teachers of Mathematics. (1984). Computers in Mathematics Education. National Council of Teachers of Mathematics in 1983 Yearbook, Reston, VA: The Council.
- National Council of Teachers of Mathematics. (1985). The secondary school mathematics curriculum. National Council of Teachers of Mathematics 1984 Yearbook, Reston, VA: The Council.

- National Science Board Commission on Prescolleage Education in Mathematics, Science and Technology (1983). A Report to the American People. Washington: The Science Board.
- Noddings, N. (1985) "Formal Modes of Knowing" Ch.VII of Learning and Teaching the Ways of Knowing. Part II 84th Yearbook of the National Society for the Study of Education, Chicago, Ill.: University Chicago Press
- Ontario Ministry of Education (1984) Ontario Schools Program and Diploma Requirements 1984. Toronto: Ministry of Education.
- Papert, S. (1980) MINDSTORMS: Children, Computers and Powerful Ideas. New York: Basic Books.
- Peccei, A. (1982) One hundred Pages for the Future. Reflections of the President of the Club of Rome. London, England: Futura Publications.
- Romberg, T. A. (1983) "A Common Curriculum for Mathematics". Ch. VI of Individual Differences And The Common Curriculum 82nd Yearbook of the National Society for the Study of Education, Part I, Chicago, Illinois: University of Chicago Press 1983.
- Sawyer, W. W. & Srawley (1957). Designing and Making. Oxford: Blackwell
- Schoenfeld, A. H. (1985) Mathematical Problem Solving New York: Academic Press Inc.,
- School Curriculum Development Committee (1986). Primary Mathematics Project (PRIME) 45 Nottingham Gate, London: Information Centre, SCDC.
- Shuard, H. (1986) "Primary Mathematics Towards 2000" Presidential Address to the Mathematical Association Conference, Easter 1986. Leicester: The Mathematical Association.
- Skemp, R. R. (1971) The Psychology of Learning Mathematics. Middlesex, England: Penguin Books.
- Skemp, R. R. (1976) "Relational Understanding and Instrumental Understanding". Mathematics Teaching No. 77, Sept. 1976.
- Skemp, R. R. (1979) Intelligence, Learning and Action: A Foundation for Theory and Practice in Education. New York: Wiley and Son.
- Skemp, R. R. (1982) "Symbolic Understanding". Mathematics Teaching No. 99, June 1982, 59-61.
- United Nations Educational Scientific and Cultural Organisation (UNESCO) (1985). Reflections on the Future Development of Education. Paris: Unesco.
- University of Chicago School Mathematics Project (UCSMP) (1985) Booklet outlining the Project. Chicago, Ill.: UCSMP (1985).
- Usiskin, Z. (1985) "We Need Another Revolution in Secondary School Mathematics" in The Secondary School Mathematics Curriculum-1985 NCTM Yearbook.
- Weir, S. Cultivating Minds - A Logo Casebook (1987). New York: Harper and Son.

Metacognition and
Mathematical Problem Solving

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Introduction

Why is it that some people are good problem solvers and others are not? Historically, educators have always been interested in individual differences. Thus it is natural to expect that this interest would extend to problem solving. (Lester, 1982, p. 57)

According to mathematics educator, F. Lester, researchers in mathematics education should focus their attention toward understanding the differences between expert and novice problem-solving behavior.

In the past, studies involving expert behavior have been conducted in such areas as business (Isenberg, 1984), chess (Chase & Simon, 1972; Chi, 1978), mathematics (Schoenfeld, 1981), medicine (Elstein, Kagan, Shulman, Jason and Coupe, 1972), physics (Larkin, McDermott, Simon and Simon, 1980; Simon and Simon, 1978) and reading (Baker & Brown, 1984; Brown, 1978, 1980). In each instance, researchers tried to identify those qualities or characteristics that make an individual an expert in his/her field, the strategies used by them, and also if these skills can be taught to others.

In general, this paper will discuss some of the aspects involved in a research study dealing with the

nature of expertise involved in mathematical problem solving. In particular, it will examine the problem-solving behavior among Ph.D. (or its equivalent) mathematicians (i.e., experts) in relation to solving complex problems and also examine these individual experts' beliefs of person, strategy and task variables in relation to mathematics, mathematical problem solving and their problem-solving behavior.

Background

The major part of every meaningful life is the solution of problems; a considerable part of the professional life of technicians, engineers and scientists, etc. is the solution of mathematical problems. It is the duty of all teachers and teachers of mathematics in particular, to expose their students to problems much more than to facts. (Halmos, 1980, p. 523)

As noted by the prolific mathematics expositor Paul Halmos, the importance of mathematical problem solving and the ability of students to solve mathematics problems, has become increasingly a major concern of mathematics educators today. This concern has been echoed at mathematics conferences, by mathematicians, by psychologists and by many mathematics educators. In particular, the National Council of Teachers of Mathematics, (NCTM), in its publication, "An Agenda for Action" stated, "The development of problem-solving ability should direct the efforts of mathematics educators through the next decade" (NCTM, 1980, p.2).

In order to meet this challenge, the mathematics

education community has conducted extensive research in mathematical problem solving over an extended number of years. In the past, many mathematics educators paid particular attention to capturing the strategies students use in solving mathematics problems. Traditionally, these studies involving mathematical problem solving have focused primarily on the overt behavior exhibited by subjects as they solved various types of mathematics problems. In general, introspective, retrospective and thinking aloud techniques have served as the main sources of gathering information and data. The analysis of these data have largely consisted of using a string of coded symbols, which acted as a trace of the problem-solving behavior exhibited by a subject during the solution process.

As a result of these studies, researchers identified successful strategies or heuristics used by subjects on various mathematics problems. "A heuristic is a general suggestion or strategy, independent of any topic or subject matter, which helps problem solvers approach, understand and/or efficiently marshal their resources in solving problems" (Schoenfeld, 1979c, p. 37).

Schoenfeld (1979a, 1979b, 1980, 1982) conducted a number of experiments in mathematical problem solving and found that students (college level) can be taught to understand and effectively use a limited number of heuristics in solving mathematics problems. He also recognized that heuristic fluency may not be enough in a

mathematical problem-solving situation and that knowing "when" and "how" to properly use a heuristic may be equally important for problem-solving success.

Therefore, in order to understand how to "properly manage" heuristics, Schoenfeld (1981) studied and compared the problem-solving behavior of "experts" and "novices" as they solved the same mathematics problems. He realized that two types of decisions are evident in the decision-making processes involved in mathematical problem solving, tactical and managerial decisions.

Tactical decisions are decisions involving the implementation of various algorithms and heuristics while managerial decisions are decisions which have a major impact upon the solution of the problem (Schoenfeld, 1981). Managerial decision making includes skills such as checking, monitoring and evaluating the entire solution process.

Schoenfeld (1981) found that experts (Ph.D. mathematicians) possess accurate and efficient managerial skills while novices (college mathematics students) lack them. Also, he found that proper managerial skills can provide the key to success in a mathematical problem-solving situation and are similar in nature to metacognitive skills. Therefore, in order to better understand the decision-making processes involved in mathematical problem solving a thorough investigation of the phenomenon of metacognition seemed appropriate.

A Conceptual Framework for the Study

In general, the term metacognition refers to two separate but related concepts: 1) knowledge and beliefs about cognitive phenomena and 2) the regulation, control and execution of cognitive actions (Garofalo and Lester, 1985). The development of the study of metacognition can primarily be attributed to the work of two researchers whose findings are complementary, John Flavell and Ann L. Brown. According to Flavell (1976),

"Metacognition" refers to one's knowledge concerning one's own cognitive processes and products or anything related to them... Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects on which they bear, usually in the service of some concrete goal or object (p. 232).

In order to study human behavior, Flavell (1979) developed a model of cognitive monitoring or metacognition, which can be applied to various cognitive enterprises. He proposed that the monitoring of many cognitive tasks occurred through the activities among four classes of phenomena: 1) metacognitive knowledge, 2) metacognitive experiences, 3) the goals of the task and 4) the actions taken on the task.

Briefly, metacognitive knowledge consists mainly of beliefs and/or feelings about certain variables (person, strategy and task) and how they act and interact with each other to influence a cognitive enterprise. Metacognitive experiences are any conscious realizations, whether

cognitive or affective, that may occur during any intellectual enterprise. The goals of the task refer to the objectives or unknowns of the cognitive enterprise and the actions of the task refer to the cognitive actions used to achieve the goals of the task.

In particular, metacognitive knowledge is similar to knowledge stored in long term memory. It consists of beliefs about particular variables and how they interact with each other to guide and/or influence any intellectual task. According to Flavell (1979), the three categories of variables associated with metacognitive knowledge are: 1) Person, 2) Strategy and 3) Task.

Person variables are everything a person comes to believe or feel about himself/herself in relation to his/her own cognitive processes and the task at hand. Strategy variables consist of strategies (tactical and/or managerial) that are likely to influence the task at hand. Task variables consist of any cues or information in the task which may trigger certain beliefs about particular strategies or demands of the task.

For example, when an individual is presented with a mathematics problem to solve, the action taken on the problem is influenced (positively or negatively) by that individual's metacognitive knowledge (i.e., by the beliefs about person, strategy and task). In general metacognitive knowledge guides and/or influences an individual to select, revise, abandon, pursue and evaluate strategies throughout

the solution process (Flavell, 1979).

Another major source of information concerning metacognition is based upon the research of cognitive psychologist, Ann L. Brown. According to Brown (1980),

The skills of metacognition are those attributed to the executive in many theories of human memory and machine intelligence, predicting, checking, monitoring, reality testing and coordination and control of deliberate attempts to study, learn or solve problems (p. 454).

At this point, it should be noted that Brown's understanding of metacognitive skills is analogous to Schoenfeld's concept of proper and efficient managerial skills (i.e., skills such as monitoring, assessing and checking the solution process throughout the entire problem-solving episode).

Therefore, in order to examine the problem-solving behavior among experts, a framework for investigating an individual's metacognitive knowledge (devised through the works of Flavell, Brown and Schoenfeld) was used in this study.

A Research Study: An Overview

The study was descriptive in nature involving expert problem solvers in relation to metacognition and mathematical problem solving. The subjects selected for this study (n=16) were divided into two categories - group A (Ph.D., or its equivalent, mathematicians who have achieved national or international recognition in the mathematics community) and group B (Ph.D. mathematicians who have not

achieved such recognition).

Information collected during the study was gathered from two sources: 1) a Person-Strategy-Task (P-S-T) Questionnaire (Appendix A) and 2) a Problem-Solving Task Booklet (Appendix B).

The purpose of the P-S-T Questionnaire was to examine and contrast an experts' metacognitive knowledge and mathematical beliefs in relation to mathematics and mathematical problem solving. The questionnaire consisted of 10 open-ended questions with some subquestions. Each subject's tape-recorded responses were transcribed, and then coded, on a coding system developed by the researcher.

The purpose of the Problem-Solving Task Booklet was to describe the various strategies exhibited by the subjects as they solved four mathematics problems. Each subject was instructed to "think aloud" as he solved each problem and immediately after was asked a series of question in connection with his problem-solving behavior on that problem. The entire session was tape recorded and each session was transcribed and coded using a coding system adapted from Schoenfeld (1981).

A Brief Discussion of the Results

In general, the results of the study seemed to indicate:

- 1) subjects in group A solved the problems more accurately (30 correct and 2 incorrect in group A VS. 8 correct and 24 incorrect in group B) and exhibited more efficient metacognitive skills on the problems than their counterparts

in group B, 2) the metacognitive knowledge and mathematical beliefs held by subjects in group A was dissimilar to that of subjects in group B and 3) a subject's metacognitive knowledge seemed to influence, in a subtle way, his problem-solving performance.

In order to understand how and why a subject's metacognitive knowledge may have influenced his problem-solving performance, a case study is discussed next.

A Case Study

During many problem-solving situations, both aspects of the definition of metacognition interact and effect an individual's problem-solving behavior during a solution process. For example, an individual may possess certain beliefs about mathematics (part 1 of the definition of metacognition) which may effect his/her control and execution (part 2 of the definition) on a problem, which in turn may trigger other beliefs, etc.

On the issue of monitoring and controlling one's work, Schoenfeld (1985a) stated,

... having a mastery of individual heuristic strategies is only one component of successful problem solving. Selecting and pursuing the right approaches, recovering from inappropriate choices and in general, monitoring and overseeing the entire problem-solving process, is equally important. One needs to be efficient as well as resourceful. In broader terms, this is the issue of control (pp. 98-99).

Therefore, the ability of an individual to "keep in control" of his/her work during the entire solution process

seems to be an important aspect of successful problem solving.

This case study presents the problem-solving performance of John (a fictitious name and an individual who participated in the study) on problem 2 (Schoenfeld, 1983, Appendix B). It illustrates how an individual's knowledge and beliefs about mathematics and his ability to control his work during the solution process positively influenced his problem-solving performance.

The question and John's response to it are given next. An analysis (adapted from Schoenfeld's work, 1981) and a discussion of his problem-solving performance follows the problem-solving protocol.

Estimate as accurately as you can, how many cells might be in an average-sized adult human body. What is a reasonable upper estimate? A reasonable lower estimate? How much faith do you have in your figures?

Problem-Solving Protocol

Estimate, as accurately as you can, how many cells might be in an average-sized adult human body? What is a reasonable upper estimate? A reasonable lower estimate? How much faith do you have in your figures? . . . (1)

OK . . . it's a pretty reasonable question . . . (2)

So . . . my reaction is two ways to approach it, linear dimensions or mass of the . . . cells . . . (3)

OK . . . so I would guess that . . . if I try it by mass . . . I would guess that . . . that an adult human weighs 150 pounds . . . (4)

There's a pretty big hunk of him which I guess isn't really to be counted as cells . . . there might be fifty pounds of that . . . (5)

So maybe there's a hundred pounds of cells . . . (6)

Now, how much is a cell going to weigh . . . (7)

Basically, I'd guess that a cell . . . it is going to weigh what? . . . (8)

First, I've got to think about how big they are . . . they're going to have the mass as that of water, so it's just a question of volume and . . . to all reasonable degrees . . . I mean obviously we're not going to try and get within ten percent so . . . it's certainly not going to matter . . . make a ten percent error . . . assuming that the mass of all cells is simply proportional to water of the same weight . . . (9)

So . . . I've got to think about how big a cell is . . . (10)

Obviously they do vary but . . . (11)

I certainly don't carry this around in my head . . . I would say a hundred kilometers . . . (mumbled) . . . would be about right . . . (12)

That would be ten microns . . . some of them are probably smaller than that but . . . (13)

Let me just think about . . . about what . . . kind of magnification it takes to see them . . . yes, that's within reason . . . (14)

So I'm taking a guess that they're a hundred . . . they're . . . they're little cubes a hundred . . . a hundred to a millimeter . . . so there are ten to the fifth to a meter . . . (15)

So there are ten to the fifteenth in a cubic meter . . . (16)

A cubic meter of water weighs, what is ordinarily called a ton . . . (17)

And so . . . there is ten to the fifteenth in a ton and we were talking about a hundred pounds so . . . (18)

There are ten to the fifteen over twenty . . . (19)

And the number is about one-half of ten to the fourteenth . . . (20)

Five times ten to the thirteenth is a good fair guess, five times ten to the thirteenth . . . (21)

Roughly . . . one hundred pounds . . . equals one-twentieth of a cubic meter of water . . . (22)

And approximately one-twentieth times ten to the fifteenth cells . . . (23)

That's . . . can't be too far wrong . . . (24)

Now, what sort of faith would I want to put in that . . . (25)

Well . . . I could see my error in how big a cell is . . . off easily be a factor of three . . . (26)

So that got cubed . . . (27)

So I think twenty plus or minus in either direction, I'd have to guess might be a fair . . . error . . . (28)

But, I haven't seen this problem . . . (29)

Analysis

John read the problem and correctly identified the conditions and the goals of the problem (1).¹ He commented at the end of the session that he did not recall ever attempting to solve this problem (29).

Immediately after reading the problem, John was concerned with which approach to use on the problem.

1. Working with the linear dimensions of the cell; or,
2. Working with the mass of the cell (3).

Each approach was relevant to the solution and he chose to work with the mass of the cell (4).

In implementing this plan, John estimated the average-sized adult human body consisted of 100 pounds of cells. Next, he realized he had to estimate the weight of a cell (7-8) which led him to estimate the linear dimensions

¹. Numerals in parentheses refer to statement numerals in Problem-Solving Protocol.

of a cell (9-10). His estimate of the dimensions of a cell (12-15) was based upon the magnification needed to see a cell through a microscope (14).

At this point, John returned to his original plan and its implementation followed in a logical, structured manner and was monitored throughout the entire solution process. Conscious metacognitive statements can be found in (7-11) and (14).

In the end, John stated his answer (21), checked his work (22-23) and was satisfied with his solution. He took approximately 2 minutes and 50 seconds to give his complete solution.²

Discussion

In this example, the decision-making processes employed by John were very effective in obtaining the correct solution. For example, the managerial decision making (i.e., choosing to work with the mass of the cell) was a well thought out and planned process. Implementation of the plan (i.e., the tactical decisions) was carried out in a highly efficient and accurate manner. Overall, the problem-solving behavior exhibited by the subject was well planned, monitored and assessed for accuracy and

2. For purposes of this study, John's solution was considered correct but a search through various journals and books produced various solutions. I encourage the reader to try and find his/her own solution to this problem.

Belief 5: He believes the ability to use analogies and quickly recollect similar problems is important for successful mathematical problem solving. (41, 5)

Belief 6: He believes it is important to review ideas and facts (that "keep popping back into my head") in preparation for future mathematical problem solving. (45)

In this case, John believes the use of analogies (belief 5) and flexible thinking (belief 1) are important factors involved in successful problem solving. Also, he believes in using alternative methods in solving mathematical problems in preparation for future problem solving (belief 4). Therefore the cumulative effect of linking together beliefs 1, 4 and 5 may help explain "why" and "how" John was able to generate and state various approaches to this problem.

In general, this problem requires the problem solver to recall and utilize information stored in long term memory and therefore having a "good memory" contributes significantly toward obtaining a correct solution.

In this case, combining beliefs 2, 3 and 6 resulted in John's ability to choose an efficient plan and implement it correctly.

It seems as though the beliefs acquired by John in relation to mathematics and mathematical problem solving played a strong and positive role in his decision-making processes and his overall problem-solving performance.

(DeFranco, 1987, pp. 43-45)

Conclusion: Implications for Teaching Mathematics

The results of this study support Polya's (1973) suggestions on becoming a better problem solver, and therefore his suggestions are invaluable tools for mathematics teachers.

For example, according to question 5 of the P-S-T Questionnaire (Appendix C) (i.e., . . . What general strategies or techniques do you think you would use to help you toward the solution of a problem?) the most frequently cited response was the "use of analogies". This response is identical to Polya's suggestion of "recalling a similar or analogous type problem". Also, many of the responses given by the subjects to this question correspond to the list of heuristics prescribed in his book.

In question 6 of the P-S-T Questionnaire, (i.e., When do you rework and use or not use alternative methods to solve a problem?), 12 out of 16 subjects responded almost always or that they would use alternative methods under certain conditions relating to the problem.

In his book, Polya (1973) presents a four-step model or framework which can be used as a guide to help an individual become a better problem solver. In the last phase of his model (i.e., Looking Back) Polya instructs the reader to rework problems (i.e., by using alternative methods, by changing the conditions of a problem, by changing the goal of a problem, etc.) and therefore, the responses by the subjects to question 6 parallel the last phase of Polya's problem-

efficiency throughout the entire solution process.

The protocol demonstrates that John's ability to regulate and control his actions on this problem (i.e., part 2 of the definition of metacognition) were instrumental in helping him attain a correct solution.

What else could explain his actions on this problem? A set of beliefs (i.e., information associated with John's metacognitive knowledge) may have guided or influenced his problem-solving behavior (in a positive way) on this problem.

After examining John's responses to some of the questions on the questionnaire (see the Person-Strategy-Task Questionnaire in Appendix C, it seems that John has acquired the following beliefs:

Belief 1: He believes one of the most important characteristics of an expert problem solver is to be flexible and to think of various approaches to a problem.
(Question 1 (Q1))

Belief 2: He trusts his memory for mathematical facts. (Q2a)

Belief 3: He believes having a "good memory" is important for successful mathematical problem solving.
(Q2b)

Belief 4: He believes it is important to use alternative methods in solving mathematics problems in preparation for future mathematical problem solving.
(Q6a)

solving model.

What are the implications for teaching gathered from the responses to questions 5 and 6? To begin with, the study has indicated expert problem solvers believe they rely on analogies to solve mathematics problems. Therefore, how mathematical information is received, stored and accessed from memory are evidently crucial issues involved in successful problem solving.

For example, according to information processing models of human behavior, an individual receives information into short-term memory (STM). This information is usually "chunked" (i.e., individual bits of information that are familiar or recognizable by an individual) and processed into STM in milliseconds. An individual can usually take in about 4 chunks at any one time. Next, if the information is to be placed into long-term memory (LTM) then the individual must fixate on the chunk of information to be stored for approximately 8 to 10 seconds (Simon, 1980).

Therefore, if students are to receive, store and access mathematical information properly, mathematics teachers must give students the necessary time to digest and reflect on new mathematical information.

Next, according to the responses from questions 5 and 6, it seems mathematics teachers should expose their students to the experience of doing many different problems. Also, they should teach them to understand the underlying structure of a mathematics problem, in order to improve the

student's ability to recognize strategies for solving similar type problems.

Mathematics teachers should routinely lead their students to discovering various alternative approaches to mathematics problems and train students how to recall these analogies. This would create a reservoir of similar type problems that could be helpful for present and future problem-solving endeavors.

Another implication for teaching, deals with teacher-student mathematical belief systems. From this study, it seemed mathematical beliefs held by Ph.D. mathematicians influenced (positively or negatively) their problem-solving performance on various mathematics problems. Therefore, it is natural to assume that the mathematical beliefs (and beliefs in general) held by students may influence their mathematical problem-solving behavior.

To begin with, what is meant by the term "a belief system"? According to Rokeach (1960).

The belief system is conceived to represent all the beliefs, sets, expectancies, or hypotheses, conscious or unconscious, that a person at a given time accepts as true of the world he lives in. (p. 33)

What influence do teacher's beliefs about mathematics and mathematical problem solving have on a student's problem-solving performance? Thompson (1982) examined three junior high school teachers conceptions of

mathematics and teaching in relation to their instructional practice. She found,

...the teachers' views, beliefs, and preferences about mathematics and its teaching played a significant, albeit subtle, role in shaping the teachers' characteristic patterns of instructional behavior. (p. 285)

Therefore, if a teacher's views and beliefs about mathematics play a role in his/her instructional behavior then it seems that various beliefs about mathematics and mathematical problem solving will be communicated to the student. Therefore, students will acquire many beliefs and misbeliefs about mathematics.

For example, from this study, it seemed that many of the subjects felt that having a "good memory" was necessary for successful problem solving. On the other hand, if an individual acquires the belief that having a "bad memory" may prevent him/her from solving a problem then this belief may help explain an individual's lack of perseverance on a problem.

Also, from the subjects' responses, areas such as confidence, interest, a "love" of doing mathematics and an overall positive attitude toward mathematics, etc. seemed to contribute to successful mathematical problem solving. Therefore, these qualities should be stressed while teaching mathematics.

On the issue of practical suggestions for teachers dealing with beliefs, Schoenfeld (1985b) stated:

...the real difficulty comes in helping students to remove inappropriate beliefs or ideas: those beliefs must be discovered before they can be removed ... Mis-beliefs are only likely to surface if students are given the opportunity to show us what they 'know'. In the classroom I have found that the most effective way to find out what lies beneath the surface of students' performance is to repeat in different forms, one simple question: 'Why?'. (p. 375)

Therefore, mathematics teachers should be aware of their beliefs about mathematics and mathematical problem solving and present mathematics in such a way that fosters and reinforces a positive mathematical belief system in each student.

A final implication for teaching from the results of this study deals with the phenomena of metacognition. In general, from the problem-solving protocols of the subjects in this study, it seemed that many of the subjects used a variety of metacognitive skills when solving the problems. For example, in many of the cases when a subject did a problem correctly, he checked, monitored and evaluated his work throughout the entire solution of the problem.

In an analogous way, the ability of students to create an internal dialogue and interrogate themselves concerning their knowledge of mathematics and mathematical problem solving may be a necessary skill for problem-solving success. A few simple metacognitive prompts during the solution process may help a student avoid inappropriate actions on a problem and may guide him/her into selecting, revising, abandoning and

pursuing proper strategies for the solution of the problem.

Therefore, mathematics teachers should incorporate into their teaching style (in a natural way), a method of questioning that demonstrates and encourages students to reflect and introspect about their work during the solution of a problem. This may establish a method in which students learn how to properly manage their knowledge, thereby, improving their problem-solving ability.

Appendix A
Person-Strategy-Task
Questionnaire Booklet

1. Please describe the qualities, characteristics or factors that you think make an individual an expert problem solver in mathematics.
- 2a. Suppose you are asked to solve a mathematics problem (i.e. either a research problem or a textbook problem and one that you do not recall doing before). How does your memory for facts, information, theorems, etc., affect your problem solving?
- 2b. What effect do you think this fact (i.e. your answer to part a) may have upon your ability to solve the problem?
- 2c. Why?
- 3a. Suppose you are asked to solve a mathematics problem and immediately after reading the problem, you realize that you do not think you have enough knowledge to solve the problem. What effect do you think this fact might have upon your ability to solve the problem?
- 3b. Why?
- 4a. Do you consider yourself to be an expert problem solver in mathematics?
- 4b. Why?
5. Suppose you are asked to solve a mathematics problem (i.e. either a research problem or a textbook problem and one that you do not recall doing before). What general strategies or techniques do you think you would use to help you toward the solution of the problem?
- 6a. After solving a mathematics problem, when do you rework and use or not use alternative methods to solve the problem?
- 6b. Why?
7. Please describe the type(s) of mathematics problem(s) you enjoy and usually work on.

8. Please describe the type(s) of mathematics problems you do not enjoy and do not usually work on.
- 9a. Which areas or branches of mathematics do you feel MOST confident working in?
- 9b. Suppose that a mathematics problem you are working on falls in one of the areas or branches of mathematics you feel MOST confident working in. What effect, do you think this would have upon your ability to solve the problem?
- 9c. Why?
- 10a. Which areas or branches of mathematics do you feel LEAST confident working in?
- 10b. Suppose that a mathematics problem you are working on falls in one of the areas or branches of mathematics you feel LEAST confident working in. What effect, do you think this would have upon your ability to solve the problem?
- 10c. Why?

Appendix B
Problem-Solving
Task Booklet

Question 1

In how many ways can you change one-half dollar?

Question 2

Estimate, as accurately as you can, how many cells might be in an average-sized adult human body. What is a reasonable upper estimate? A reasonable lower estimate? How much faith do you have in your figures?

Question 3

Prove the following proposition:
If a side of a triangle is less than the average of the two other sides, then the opposite angle is less than the average of the two other angles.

Question 4

You are given a fixed triangle T with Base B . Show that it is always possible to construct, with ruler and compass, a straight line parallel to B such that the line divides T into two parts of equal area.

Appendix C
Excerpts from the Person-Strategy-Task
Questionnaire

Question 1 (Q1): Please describe for me the qualities, characteristics or factors that you think make an individual an expert problem solver in mathematics.

Response: I think one of the main problems for the problem solver is to . . . not be locked onto a single approach. So one has to sort of relax and . . . think of a lot of possibilities at once, that's certainly one important way to look at it. Certainly one of the most important factors is experience . . . it's remarkably common to find . . . that a problem that you've been asked is quite similar to some old problem and if you have the ability to quickly recollect another problem which is similar or possibly even exactly the same obviously that's a great advantage . . . this is all a question of just thinking fast basically . . . thinking over the various possible approaches which you know, the more experience you have the more . . . you can draw on to, to give yourself possibilities of ways of thinking about it. I think about that it is very useful to use analogies . . . of various sorts, sometimes one can, can translate a problem into another context and see that you have an equivalent problem . . . where the . . . the answer is somewhat more obvious on perhaps some physical grounds or something of that sort. But overall I would say experience and fast thinking are the most important considerations.

Question 2a: Suppose you are asked to solve a mathematics problem (i.e., either a research problem or a textbook problem and one that you do not recall doing before). How does your memory for facts, information, theorems, etc., affect your problem solving?

Response: Well obviously . . . very strongly. But exactly how is not entirely clear to me . . . As I said a moment ago the first thing one does is try to think about analogies in one sort or another and to think over other problems which if not exactly the same are at least close . . . and . . . then bring in theorems . . . I certainly don't feel that at any point I simply parse my way through a strong string of theorems in hopes of . . . getting there, although I certainly do . . . think about individual theorems which I know . . . without having sort of gone through a string or at least not consciously gone through a string . . . have hypothesis which are somehow related to the problem in hand.

Question 2b: What effect do you think this fact (i.e., your answer to part (a)) may have upon your ability to solve the problem?

Response: I don't know what fact you mean? . . . how does your memory . . . I don't know how it does so I don't know if that's a fact in any event. But . . . I don't see how to answer this, I mean it's perfectly clear that . . . I cast about through . . . the entire range of my experience in mathematics in so far as it appears to be relevant to . . . the problem in hand . . . and . . . without that I would have no possibility of solving the problem . . . so obviously it is all important.

Question 5: Suppose you are asked to solve a mathematics problem (i.e., either a research problem or a textbook problem and one that you do not recall doing before). What general strategies or techniques do you think you would use to help you toward the solution of the problem?

Response: Well, as I told you the only thing I can think of is to think of analogies . . . in either context, although the nature of the analogies are likely to be different. Anything which is called a "textbook problem" one automatically presumes is solvable within a relatively confined context, in the sense that, the problem if it is in fact in the textbook is likely to be in a certain chapter which has to do with integration or linear algebra or whatever, and one can often solve such a problem in that context. In other words, the context provides you a much narrower area in which you must search for analogies and strategies. Now the more general question, what kind of strategy does one use? . . . in general, how does one do it? Well certainly one of the easiest and most efficient techniques, is to take a problem when it is not totally, tightly . . . proposed. That is to say, if one wants to prove that something is true in general, certainly one of the best strategies is to consider an extremely simple special case of the problem... if you have a problem that has to do with all integers for example, start out with two. . . instead of the general $N, N = 2$, see if you can see what's going on. $N = 3$, see if you can see what's going on. By that time if it's true, you probably can see what's going on. Sometimes that of course doesn't work. Sometimes one doesn't find the real answer so to speak, the real structure underlying the thing until one's gone a long way and sometimes you get tired of that kind of stuff . . . my own strategy has been always to . . . reconsider the foundations of the issue in some sense. I very frequently spend a lot of time going over the most elementary aspects of the subject in question, in hopes of simply building my. . . reaction . . . lowering my reaction time, so to

speak, or . . . trying to somehow build an overall perspective on the kinds of issues that are at stake. I use very large, mental images of . . . all sorts of abstract concepts. I have often times had mental images which would be very difficult to describe about . . . the meaning of certain mathematical structures. Sometimes they're . . . always pictures, they're always in a sense spatial images or perhaps geometric . . . images but sometimes they're a little difficult to explain their actual relevance, so I would be hard pressed to do that. . . but I do see often times patterns, and as I say I go over the foundations of a subject trying to see how those patterns will emerge, with of course, . . . efforts to . . . see how those things could be applied to the question in hand. I have often found in my research that . . . I keep coming back to certain ideas, unable to see why they're relevant and yet in the end they do prove to be relevant. So that when I find ideas keep popping back into my head I . . . definitely make an effort to . . . review them frequently in hopes that once again . . . some idea which I don't perceive exactly the relevance of, will indeed turn out to be ok. . .

Question 6a: After solving a mathematics problem, when do you re-work and use or not use alternative methods to solve the problem?

Response: Well, this again depends a great deal on my involvement with the problem. If I'm really concerned with this problem, that is, I really am interested in knowing more about the area in which the problem occurs, then of course, I would always try to re-work the problem and try and see if there are other ways to look at it . . . many times more effective methods of looking at the problems and so on. On the other hand, there are problems like a problem which somebody poses as a sort of a dinner table "cutie" or something like that in which, you know, I solve it and that's that. I mean it's not worth my effort to go after it in more detail. But sometimes I do that anyhow for mental problems, that is, problems which are sort of cute problems which are passed around as . . . problems to think about and presumably be solved quickly by one, from one mathematician to another, not research problems but teasers. I find that . . . sometimes I do study those . . . just to try and see if I can think of other ways of getting at it and it turns out they're often many ways of getting at those problems and . . . often times when such a problem is proposed you answer it and you offer a suggestion as to how you did it and somebody, says "Oh, that's an interesting way, I thought about it this way and the other guy has an entirely different way of looking at it. So, those schemes are very useful in building your overall strategy

for mathematics solving, it's just that it gives you more experience, it gives you more . . . alternative routes to look at something . . . and obviously these are useful at all levels, the alternative route is part of the whole strategy that I mentioned earlier.

References

- Baker, L. & Brown, A.L. (1984). Metacognitive skills in reading. In P.D. Pearson (Ed.), Handbook of reading research. (pp. 353-394). New York: Longman.
- Brown, A.L. (1978). Knowing when, where and how to remember: a problem of metacognition. In R. Glaser (Ed.), Advances in instructional psychology. (pp. 77-165). Hillsdale, NJ: Erlbaum.
- Brown, A.L. (1980). Metacognitive development and reading. In R.J. Spiro, B.C. Bruce and W.F. Brewer (Eds.), Theoretical issues in reading comprehension. (pp. 453-481). Hillsdale, NJ: Erlbaum.
- Chase, W., & Simon, H.A. (1972). The mind's eye in chess. In W.G. Chase (Ed.) Visual information processing. (pp. 215-281). New York: Academic Press.
- Chi, M. Knowledge structures and memory development. (1978). In R.S. Siegler (Ed.), Children's thinking: what develops? (pp. 73-96). Hillsdale, NJ: Erlbaum.
- DeFranco, T.C. (1987). About mathematical problem solving: On the nature of expertise. New York State Mathematics Teachers' Journal, 37 (1), 41-47.
- Elstein, Kagan, Shulman, Jason and Coupe. (1972). Methods and theory in the study of medical inquiry. Journal of Medical Education, 47, 85-92.
- Flavell, J.H. (1976). Metacognitive aspects of problem solving. In L.B. Resnick (Ed.), The nature of intelligence. (pp. 221-235). Hillsdale, NJ: Erlbaum.
- Flavell, J.H. (1979). Metacognitive and cognitive monitoring—a new area of cognitive development inquiry. American Psychologist, 34(10), 906-911.
- Halmos, P.R. (1980). The heart of mathematics. The American Mathematical Monthly, 87(7), 519-524.
- Isenberg, D.J. (1984). How senior managers think. Harvard Business Review, November/December, 81-90.
- Larkin, McDermott, Simon and Simon. (1980). Expert and novice performance in solving physics problems. Science, 208, 1335-1342.
- Lester, F.K. (1982). Building bridges between psychological and mathematics education research on problem solving. In F.K. Lester and J. Garofalo (Eds.), Mathematical problem solving: issues in research. Philadelphia, PA: Franklin Institute Press.
- Lester, F.K. & Garofalo, J. (1985). Metacognition, cognitive monitoring and mathematical performance. Journal for Research in Mathematics Education, 16(3), 163-176.
- National Council of Teachers of Mathematics. (1980). An agenda for action. Reston, VA: The Council.
- Polya, G. (1973). How to solve it. Princeton, NJ: Princeton University Press. 2nd ed.
- Rokeach, M. (1960). The organization of belief-disbelief systems. In M. Rokeach (Ed.), The open and closed mind (pp. 31-53). New York: Basic Books.
- Schoenfeld, A.H. (1979). Explicit heuristic training as a variable in problem-solving performance. Journal for Research in Mathematics Education, 10, 173-187. (a)
- Schoenfeld, A.H. (1979). Presenting a model of mathematical problem solving. Paper presented at the annual meeting of the AERA, San Francisco, CA. (b)
- Schoenfeld, A.H. (1979). Teaching problem solving in college mathematics: the elements of a theory and a report of the teaching of general mathematical problem-solving skills. In R. Lesh, D. Mierkiewicz and M. Kantowski (Eds.), Applied mathematical problem solving (pp. 37-67). Ohio: Ohio State University. (c)
- Schoenfeld, A.H. (1980). Teaching problem solving skills. American Mathematical Monthly, 87(10), 794-805.
- Schoenfeld, A.H. (1981, April). Episodes and executive decisions in mathematical problem solving. Paper presented at the annual meeting of the AERA, Los Angeles, CA.

- Schoenfeld, A.H. (1982). Measures of problem-solving performance and of problem solving instruction. Journal for Research in Mathematics Education, 13(1), 31-49.
- Schoenfeld, A.H. (1983). Beyond the purely cognitive: belief systems, social cognitions and metacognitions as driving forces in intellectual performance. Cognitive Science, 7, 329-363.
- Schoenfeld, A.H. (1985). Mathematical problem solving. Academic Press, Inc. (a).
- Schoenfeld, A.H. (1985). Metacognition and epistemological issues in mathematical understanding. In E.A. Silver (Ed.), Teaching and learning mathematical problem solving: Multiple research perspectives (pp. 361-379). Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Simon, H.A. (1980). Problem solving and education. In D.T. Tuma and F. Reif (Eds.), Problem solving and education: Issues in teaching and research (pp. 81-96). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Simon, D.P., & Simon, H.A. (1978). Individual differences in solving physics problems. In R.S. Siegler, (Ed.), Children's thinking: what develops? Hillsdale, N.J., Erlbaum.
- Thompson, A.C. (1982). Teacher's conceptions of mathematics teaching: Three case studies (Doctoral dissertation, University of Georgia) Dissertation Abstracts International 43, 2267 A.

RESEARCH ON STUDENTS' ALTERNATIVE FRAMEWORKS IN SCIENCE - TOPICS, THEORETICAL FRAMEWORKS, CONSEQUENCES FOR SCIENCE TEACHING

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1. INTRODUCTION

A great deal of research has been done and still is being done in the field of students' alternative frameworks all over the world (though mainly, as far as we know, in the "western" world). A bibliography, continually updated, started with several hundred papers, articles and books, now it already contains more than 1 000 (Pfundt, Duit, 1987). Two groups of researchers have been formed, an informal one called the "Invisible College" and a Special Interest Group of the AERA (SIG "cognitive structure and conceptual change"). Although some excellent review papers (e.g. Driver, Erickson, 1983; Gilbert, Watts, 1983; Hashweh, 1986), summarizing books (e.g. Osborne, Freyberg, 1985; Driver, Guesne, Tiberghien, 1985) and bibliographies (e.g. Pfundt, Duit, 1987; Giordan, 1987) are available it has become difficult to keep track of what has been done, what is being done and what will or should be done in future. This paper tries to give some guidance in such an endeavour. A comprehensive review cannot be expected. I merely want to present some frameworks and categories which appear to be helpful (in my view) in leading to an insight into topics of research, into theoretical frameworks employed and into the consequences drawn for science teaching.

2. STUDENT'S CONCEPTIONS IN DIFFERENT CONTENT AREAS

Research on students' alternative frameworks in science is based on the idea that the conceptions the learner already holds considerably influence the learning process. Empirical research therefore started investigating students' conceptions before instruction as well as the change of these conceptions during instruction, mainly within "traditional" instructional settings. Only recently is there a rapid increase of studies in which the effect of newly developed instructional settings (new learning strategies, new setups of content and other new instructional arrangements, see chapter 6) is investigated. But until now studies of the first kind predominate. In the above-mentioned bibliography by Pfundt/Duit (1987) some 550 entries are of the first and only some 120 entries of the second kind.

It may be interesting to look at the different content areas in which empirical studies of the first kind are available (see tab. 1). It is surprising that physics' topics are so dominant. Compared with the number of studies in the area of physics, the number of studies in the areas of biology and chemistry is rather small.

A brief remark is necessary at this point. It may well be that the great dominance of physics topics in tab. 1 is partly due to the fact that my attention is concentrated on physics because I am a physics educator. But I try to compensate this "one-sidedness" as much as possible. My colleague Helga Pfundt who ran the bibliography until her death was a chemist. Now my colleague Werner Dierks provides me with articles from the field of chemistry. It is true that I do not systematically look for articles with a biological emphasis, but only recently I was provided by M. Barker and A. Giordan with bibliographies of this area which are included in tab. 1.

MECHANICS [icon] 176	force and motion/work, power, energy/speed, acceleration/gravity/pressure/density/floating, sinking
ELECTRICITY [icon] 104	simple, branched circuits/topological and geometrical structure/models of current flow/current, voltage, resistance/electrostatics/electromagnetism/danger of elect.
HEAT [icon] 47	heat and temperature/heat transfer/expansion by heating/change of state, boiling, freezing/explanation of heat phenomena in the particle model
OPTICS [icon] 40	light/light propagation/vision/color
PARTICLES [icon] 39	structure of matter/explanation of phenomena (e.g. heat, states of matter)/conceptions of the atom/radioactivity
ENERGY [icon] 27	energy transformation/ - conservation/ - degradation
ASTRONOMY [icon] 19	shape of the earth/characteristics of gravitational attraction/satellites
"MODERN" PHYSICS [icon] 5	quantum physics/special relativity
CHEMISTRY [icon] 56	combustion, oxidation/chemical reactions/transformation of substances/chemical equilibrium/symbols, formula/mole concept
BIOLOGY [icon] 40	plant nutrition/photosynthesis/osmosis/life/origin of life/evolution/human circulatory system/genetics/health/growth
Tab.1: Studies on students' conceptions in different areas (the figures give the number of articles contained in the bibliography by Pfundt/Duit (1987) in a certain area)	

About 550 studies are reflected in tab. 1. Do we already know enough about students' conceptions in science topics? Claxton (1986) is of the opinion that we indeed know enough about them so that there is no need for further studies investigating conceptions. I think Claxton is only right if one takes the point of view of a researcher who wants to develop a somewhat comprehensive (general) theory of learning science. Indeed the research findings available so far allow us to understand main general aspects of learning difficulties. They do provide, for instance, much empirical evidence for one of the basic ideas of the constructivistic view of learning, namely that conceptions considerably influence perceptions (e.g. observations) (see e.g. Karmiloff-Smith, Inhelder, 1976; Gauld, 1986). Many other examples of this general kind could be given. Indeed, there is much empirical evidence available which allows a new general view of teaching and learning science to be developed.

But Claxton (1986) is not right if one takes the point of view of a teacher or a science educator who wants to prepare or to plan instruction for a specific science topic. Of course, general considerations on aims of science instruction and on the role of students' conceptions in the learning process may guide the planning process and instruction in the classroom. But very specific knowledge of students' conceptions in the specific content area is necessary. This is especially true if Claxton (n.d.) is right (and I think he is) that students' conceptions (Claxton speaks of "mini-theories") are content-specific.

A brief look at tab. 1 from this point of view reveals that there are many topics relevant in science instruction in which nothing or little is known about students' conceptions. That is obviously true for the areas of biology and

chemistry, where only a small total number of studies is available. But it is even true for the area of physics. Of course, there are certain topics where enough studies are available. I think, for instance, that further studies will not reveal too much new information on students' ideas of force. But also in fields where many studies are available (such as mechanics and electricity) there are still important topics (such as electromagnetic induction in the field of electricity) which have not been investigated so far. Other fields of physics, such as magnetism and sound, appear to have missed out on any, at least any considerable attention so far. I hold, therefore, that further research on students' conceptions of the first kind is necessary in order to provide teachers and science educators with sufficient knowledge of possible students' conceptions in all relevant areas of science. Tab. 1 may guide such a research in order to avoid "butterflying through the curriculum" (Pines, West, 1986), i.e. research sucking one misconception here, another there.

3. STUDENTS' CONCEPTIONS OF DIFFERENT DOMAINS

Research in our field is mainly based on a constructivistic view of learning, i.e. on the idea mentioned above that students' conceptions considerably influence learning and the idea that students have to construct their knowledge actively (see some further remarks on the constructivistic view below). It is interesting to analyze which kind of conceptions have been given attention in research so far, i.e. which kind of conceptions have been viewed as most relevant concerning learning science.

A first reduction is remarkable. Although a constructivistic view of learning underlines the importance of the affective

domain, the cognitive domain has been given and still is given almost exclusive attention. In the cognitive domain there are some important reductions too. The overwhelming majority of studies concentrate on science concepts, i.e. on conceptions of science topics (see the overview in tab. 1). Studies on science processes are rarely to be found (for an approach taking students' conceptions of the range and the nature of science concepts into consideration see Niedderer, 1982, Schecker, 1985).

Whereas science processes are not given much attention there are some attempts to detect general "modes of thinking" which may "stand behind" students' conceptions of specific science topics. Jung's research program, for instance, is a remarkable example of such an attempt. Behind the great number of investigations of conceptions in the areas of electricity, mechanics, heat and optics there is the search for general "modes of thinking" such as schemas like the "give-schema" (see Maichle, 1981) or general categories of thinking like thinking in the category of relation (which is of great importance in science, see Jung, 1979). Another attempt which shall be mentioned here is Andersson's (1986) interpretation of conceptions in different content areas within the framework of "experiential gestalt of causation". Di Sessa's (1985) interpretation of students' conceptions in the area of "force and motion" within his framework of "phenomenological primitives" (see below) leads into a similar direction.

A brief remark on recent research attempts will conclude this section. There are some studies now which go beyond students' conceptions of science concepts, science processes or general "modes of thinking", namely investigating how students view what is going on in classroom (e.g. how they view the role of experiments they perform) and how they view their own

learning process (see e.g. Tasker, Freyberg, 1985; Mitchell, Baird, 1986; further see some additional remarks in chapter 6).

4. THEORETICAL FRAMEWORKS OF RESEARCH. PART I: THE MANIFOLD TERMS USED TO INDICATE STUDENTS' CONCEPTIONS

Many terms are used to indicate what this paper so far has called students' conceptions. In the following I try to provide an overview of such terms. Although I do not mention all terms used in the literature I hope to mention the ones which indicate the most important positions of research. The purpose of the overview is not simply to show how a plethora of names can be given to almost exactly the same thing. I hope that the main lines of thought within our research area become visible. In order to understand the different positions appropriately it may help to be reminded of the fact that researchers of rather different points of view are cooperating in our field. On the one hand there are those researchers who are interested in general aspects of thinking and learning (e.g. problem solving-strategies). They investigate students' conceptions in the area of science for the sake of developing their general theories. On the other hand there are science educators who are interested in guiding students to science. They investigate students' conceptions with the aim of improving science learning. Of course, there is a considerable overlap in the interests of the two groups. But there are also considerable differences which lead to different emphasis on specific aspects.

Conception. This term has been used in this paper so far for good reasons. In my view it appears to be the most "neutral" term. It indicates that the learner forms a "mental representation" of the world outside himself. Such a mental representation facilitates an understanding of this outside

world and of the behaviour appropriate within it. Conception appears not too far removed from what usually is called a concept. The difference seems to be that conceptions are somewhat looser or vaguer than concepts. **Preconceptions** indicate the conceptions students have formed before instruction.

Conceptual Framework. "By the construct 'conceptual framework' we shall mean the mental organization imposed by an individual or sensory inputs as indicated by regularities in an individual's responses to particular problem settings" (Driver, Erickson, 1983).

Conceptual framework appears to be not too far from what has been called conception here. The difference seems to be that conceptual frameworks are of a rather more general nature, i.e. do not indicate single, very specific conceptions.

Construct. This is a term stemming from a constructivist point of view (see e.g. Kelly, 1955). The meaning is more or less the same as the meaning of conception if the above statements on conception are given a constructivist meaning, i.e. the idea is taken that every student has actively to construct his "mental representation" of some part of the world outside.

Misconceptions. Misconceptions are conceptions which are incorrect viewed from the standpoint of science. Quite often a value judgement is connected with the use of this term: the science conceptions are the only ones which can be tolerated, the misconceptions have to be erased. Because the great majority of researchers in our field do not take such a traditional "hardliner's" point of view the term misconception is avoided by quite a considerable number of them. Some give it specific meanings. Nachtigall (1986), for instance, terms misconceptions incorrect conceptions (seen from the science point of view), which have been formed by science instruction itself. Recently the aspect indicated by the prefix "mis" appears to be discussed under the heading of "students' errors" (see e.g. Fisher, Lipson, 1986).

Alternative framework. This term has been proposed by Driver and Easley (1978) as reciprocal to the term misconception and its above mentioned "traditional" view of science. The term, therefore, stands for a program with which most researchers in our field will agree: students' conceptions are no longer viewed as conceptions which have to be erased in science instruction as fast as possible but they are viewed as conceptions in their own right. In many everyday situations they are, for instance, most helpful. Quite often they are in such situations more helpful than science conceptions.

Children's science. This term also indicates that children's conceptions are in their own right. It starts from Kelly's (1955) "man-the-scientist" idea, i.e. from the idea that the mental constructions of all human beings are in principle quite comparable to the constructions of scientists. Children, therefore, are also scientists, though of course only within the limited range of their state of development (see e.g. Gilbert, Osborne, Fensham, 1982).

Mini-theory. Claxton (n.d.) follows the idea of the child as a scientist too, "theory" indicates this. "Mini" stands for the fact that most students' conceptions do have only a rather small range of validity. Mini-theories are content and context specific, i.e. students hold many of these theories, each of them valid only in small content and context areas.

Idea, notion, belief. There are many other terms in use to highlight specific aspects of students' conceptions. "Idea" and "notion" indicate that students' conceptions quite often are somewhat vague. "Belief" highlights the fact that many students' conceptions have aspects of a rather deep-rooted conviction, students "believe" in them.

Schema, script, frame. There are many relations between research in our field and cognitive psychology. Therefore, terms of cognitive psychology are frequently used in students' conceptions research (for a critical review see Jung, 1985). Schema is a term already used by Piaget. In our field it is usually used in the following way (Jung, 1985): it does not indicate what Claxton (n.d.) calls a mini-theory, it is used for general "modes of thinking" such as the "give-schema" which plays an important role in many areas ("a battery, for instance, gives current, energy or something else to a bulb" according to many students' ideas in the area of electricity; see Maichle, 1981). Frames are "powerful background schemas" (Jung, 1985), i.e. conceptions which guide thinking and acting in somewhat broader areas.

Phenomenological primitive. What di Sessa (1985) has called phenomenological primitives ("p-prims") are rather general conceptions: phenomenological primitives "can be understood as simple abstractions from common experiences that are taken as relatively primitive in the sense that they generally need no explanation, they simply happen" (di Sessa, 1985). An example of a p-prim is "Ohm's Law": the bigger the drive of something the bigger is the effect and the bigger the hindrance the smaller is the effect. Phenomenological primitives are powerful "background schemas" (i.e. frames) to employ the above mentioned meaning of these terms. They form when the child is confronted with phenomena and tries to manipulate them.

5. THEORETICAL FRAMEWORKS OF RESEARCH. PART II:

THE CONSTRUCTIVISTIC VIEW OF LEARNING AS CONCURRING POSITION

The preceding part I of "Theoretical frameworks of research" has pointed out that there is considerable concurrence between researchers in our field despite manifold differences. In the past years it has become common to describe this concurrence within an constructivistic view of learning. Rather briefly sketched (for more details see Gilbert, Watts, 1983; Glasersfeld, 1983; Driver, Oldham, 1985; Watts, Pope, 1985) a constructivistic view means that human learning is viewed as a very active construction process. Learning is not seen as a process of simply storing pieces of knowledge provided by a teacher (a book or anything else). It is on the contrary seen as a process of actively constructing the knowledge by the learner herself on the grounds of her already existing conceptions.

It is interesting to follow the roots of this constructivistic concurrence" in our research field, i.e. to look at the positions employed in order to underpin the constructivistic view (see e.g. in Driver, Erickson, 1983; Gilbert, Swift, 1985):

(a) Main trends in the philosophy of science in the 60's and 70's: Hanson's (1965) idea that all perceptions are theory laden; Kuhn's (1970), Lakatos' (1970), Feyerabend's (1978) view of knowledge as relational in nature, not being "nuggets of truth" (Kelly, 1955) but being human provisional constructions.

(b) Information processing theories as have been worked out in the past 10 to 15 years (see e.g. Gentner, Stevens, 1983).

(c) Constructivistic traditions in philosophy and social sciences (see e.g. Kelly, 1955; Magoon, 1977; Watzlawik, 1981).

It is certainly not by accident that the constructivistic view became prominent during the early 80's.

There are trends of thinking in other areas which are very near to this view. The idea of self organizing systems appears to become a general way of thinking in natural as well as in social sciences (see e.g. Watzlawik, 1981). This idea is near to basic views of constructivism insofar as systems organize themselves (i.e. construct new structures) due to specific traits of their internal structure in interaction with the environment. It is, for instance, rather exciting to read Bereiter's (1985) analysis of seeming paradoxes of the constructivistic view from the point of view of basic ideas of self-organising systems, especially from the point of view of self-reference.

This idea highlights the problem how it is possible for new structures to grow up out of the system itself. This paradox is discussed at great length by Hofstadter (1979), for instance, in a book which has in some way become a "cult book" of the 80's.

The tendency of many science educators in our research field to adopt the constructivistic view expresses the need for a theoretical foundation of students' conceptions research. It would be quite an interesting task to follow this search for theory in the different research groups. The group in Surrey (Gilbert, Pope and others), for instance, started their well known and well recommended research method of "interviews about instances" (I-A-I) based on somewhat traditional ideas. One of the main references for the first description of the method (see Gilbert, Osborne, 1979) was, for instance, Klausmeier et al. (1974). When adopting Kelly's (1955) point of view they also underpinned their "I-A-I-method" with this view but without changing the method of interviewing itself to any appreciable extent. What they did change was the interpretation of the gained research data.

There is some reservation about the term "constructivistic" because some streams of constructivism in philosophy are rather near to solipcism, i.e. neglect social aspects of constructing knowledge. But in general the constructivistic view is accepted at least to a certain extent by all researchers in our field. "At least to a certain extent" means that this view does not always appear to be deeply rooted. Sometimes it is mainly or even exclusively employed when viewing students' learning, i.e. it is accepted that students have to construct their knowledge actively on the grounds of constructs already available to them. But it is overlooked that the constructivistic view has to be employed in a much broader manner. It also has to be considered that the researcher her/himself constructs the conceptions of students on the background of his/her conceptions (i.e. science knowledge, prejudices etc.). Research of students' conceptions does, therefore, always mean constructing constructions of constructions (see Marton, 1981). Thus it is not only students' science knowledge which is provisional in nature, but also the researcher's knowledge of this knowledge.

6. CONSEQUENCES FOR SCIENCE TEACHING AND LEARNING

The following chapter sets out to provide some insight into the many and varied efforts to draw conclusions from research findings as well as from theoretical positions (i.e. mostly a constructivistic point of view) gained by analyzing the research findings.

To understand the different efforts appropriately it may help to have an overview of conceptions which are of importance in science instruction. Tab. 2 tries to provide such an overview. Some additional remarks on tab. 2 may be helpful.

Media such as TEXTBOOKS which are used (but not produced by the teacher)

- (1) conceptions of science topics (e.g. energy, chemical bonding, particles, photosynthesis, nutrition)
- (2) conceptions of the nature and range of science (implicitly or explicitly embedded in the media)

SCIENCE

STUDENT

- (1) conceptions of science topics
- (2) conceptions of the nature and range of science
- (3) conceptions of the purposes, the aims of science instruction
- (4) conceptions of the purpose of specific teaching events
- (5) conceptions of the nature of the learning process
- (6) attitudes to science, to specific topics of science, to learning science, to the science teacher, to being in school, to learning in general

TEACHER

- (1) conceptions of science topics
- (2) conceptions of the nature and range of science
- (3) conceptions of the purposes, the aims of science instruction
- (4) conceptions of the purpose of specific teaching events
- (5) conceptions of the nature of the learning process
- (6) attitudes to science, to specific topics of science, to being a teacher, to the students

Tab.2: "Variables" of a constructivistic view of science teaching and learning

to (1): We know from many studies (see tab. 1) that students' conceptions very often are not in accordance with science conceptions. But we further know that textbooks' conceptions (see e.g. Nachtigall, 1986) or teachers' conceptions of science topics (see e.g. Ameh, Gunstone, 1985) are also not always correct seen from the science point of view.

to (2): These conceptions are, so to speak, meta-conceptions of what science is about. We do not know very much about students' meta-conceptions (see chapter 3) but we know something about (sometimes hidden) philosophy of science of textbooks and teachers (see e.g. Korth, Cornbleth, 1986).

to (3): That teachers' aims of teaching science and students' aims of learning science quite often do not accord is an important aspect. But so far we know very little about it which is based on empirical evidence (for some findings in this direction see Gunstone, Northfield, 1985).

to (4): Tasker and Freyberg (1985) have provided us with some research findings on the different views of teachers and students on single teaching events (e.g. experiments). Teachers usually have a long term perspective, for them a single event has its place within a structured sequence of related events. Students' quite often appear to miss such a long term perspective. They view, for instance an experiment as a single event unrelated to others.

to (5): The constructivistic view as outlined in chapter 5 led many researchers to the insight that views of the learning process is of decisive importance, teachers' view of students' learning and students' views of their own learning (see further details below).

to (6): There is no doubt that attitudes influence learning considerably. There is a great deal of research activity on students' attitudes (for a review see Gardner, 1985). But so far there appear to be only limited efforts to bring together research findings in the area of students' attitudes and students' conceptions.

Tab. 2 may guide further considerations and further research on science teaching and learning. It may also help to appraise the following kinds of consequences which have been given main emphasis so far.

(A) To change the aims of science teaching

There has been a continuous discussion of the aims of science instruction throughout the history of this discipline. There appears to be a neverending switch of emphasis on different positions. In this sense, the discussion about changing the aims of science teaching in favour of "new" ones mainly serves to remind us of positions which are given only little emphasis in our schools today.

It is difficult to summarize the different proposals to change the aims of science teaching. My view is this: An extreme position which proposes to cancel science instruction (i.e. to let students stay with their everyday conceptions which are undoubtedly of value in most everyday situations) appears to have almost no recommendations. The overwhelming majority of researchers is convinced that it is indeed of value for students to gain science conceptions. Claxton (1986) is of opinion that many researchers hold positions which are not very far from the traditional aims. He lists, for instance, implicit assumptions made by researchers which are more or less traditional ones. Claxton may be right, but only to a certain extent. It is true, I think, that most traditional science topics will also be part of the "new" curriculum on the grounds of the constructivistic view. But there will be considerable changes on the level of meta-conceptions (see (2) in tab. 2), i.e. students' conceptions of what science is about. A "constructivistic" curriculum will usually aim at a relational view of science conceptions. Quite a common idea appears to be that science instruction has to convince students that both their everyday conceptions and the science conceptions are conceptions in their own right which are valid in specific contexts only. Recent research findings have pointed out that students have severe problems in gaining such a relational view of science

conceptions. There is a strong tendency that students do not want to "play around" with different conceptions, they want to know the right (the true) one (see Driver, 1986; Mitchell, Baird, 1986).

There are research findings in the area of "complementary thinking" which indicate another important aspect (Oser, Reich, 1986). The ability of human beings to appreciate that complementary "theories" may both be valid appears to develop slowly. The majority of children in the above-mentioned study up to the age of about 16 were unable to admit that different points of view can be "true" at the same time.

The research findings mentioned need further confirmation. They are of great importance for all constructivistic teaching strategies which explicitly discuss differences between students' and science conceptions in the classroom. If students' are really not only unwilling but also unable to mentally "play around" with different conceptions which are valid in different contexts, constructivistic approaches would run into severe troubles.

(B) To change the content structure of instruction

As has been mentioned most researchers still want to guide students to science conceptions, more or less to the traditional ones. It is, therefore, an obvious decision to change the setup of content in order to avoid misunderstandings or to challenge conceptions. Many proposals for overcoming learning difficulties are of this kind. Feher and Rice (1985), for instance, challenge the conception of many children that a shadow "comes out of the body" when it stands in the light by using light sources which produce shadows which are not similar to the body any more but to the structure of the light source. Such light sources have not been part of the curriculum so far.

(C) New teaching aids

Of course, there is some hope that new teachings aids may help to overcome difficulties. The computer is particular seen as promising (see e.g. Linn, 1986, Klopfer, 1986).

(D) To change teaching strategies

There is a considerable number of proposals for teaching strategies to guide students from their preconceptions to science conceptions. Driver and Erickson (1983) have summarized the main strategies as well as research findings concerning their success. This review mainly appears to be valid up to now. The conclusion that there are encouraging as well as discouraging findings, that in general a great "breakthrough" is not in sight, appears to be still valid.

The strategies aim at what now is usually called "conceptual change". They are generally rooted in constructivistic frameworks. The strategy of Posner et al. (1982) is quite paradigmatic for most of them. It is rooted in information processing theory and in Kuhn's (1970) idea of paradigm shift. According to Posner et al. (1982) there are four conditions for conceptual change:

- dissatisfaction with existing ideas
- the new conception must be intelligible
- the new conception must appear initially plausible
- the new conception must be fruitful.

The first and the last condition have proven to be the most difficult ones for students. It is rather difficult to create dissatisfaction with existing ideas. Students are very often unable and unwilling to change their conceptions because they are quite pleased with them and because they do not see clearly enough in which respects the new conceptions are more fruitful than the old ones. Indeed science conceptions are quite often more abstract and more sophisticated than

students' conceptions. That they are in some way more fruitful is understandable only for those who are already very familiar with the science point of view (see, e.g. Mitchell, Baird, 1986; Driver, 1986).

Clark (cited in Pope, 1985) has argued against strategies of conceptual change that they are usually designed from the ultimate result of teaching, namely the science conception, and not from the needs of students.

Another problem of these strategies has already been mentioned (see (A)). They are based on the assumption that students are able to admit that both the students' conceptions and the science conceptions are conceptions in their own right, i.e. are both valid although in different contexts. Research findings appear to shake this assumption, especially for students in the 12 - 16 age-group.

(E) To employ strategies of meta-learning

As pointed out in the remarks on tab. 2, students' conceptions of their own learning process are of great importance. There are several proposals for meta-learning, i.e. for promoting students' insight into their learning processes and enhancing them by specific strategies (see e.g. Novak, 1985). Empirical studies on the impact of meta-learning strategies carried out by Baird (1986) and Mitchell, Baird (1986) have shown that there is some success of such strategies but that success is considerably limited by certain conditions of learning and that general meta-learning strategies are not so helpful as strategies accommodated to a specific content. They further report that students view such strategies, especially in the beginning, as rather boring. It would be interesting to have more studies of this kind in order to reach a conclusion whether meta-learning strategies really help to overcome difficulties in learning science.

(F) To teach teachers constructivistic ideas

Constructivistic ideas can only work in school practice if teachers are familiar with them and are convinced of their value. Gunstone, Northfield (1986) report on experiences to teach a constructivistic view of learning to teachers. They found that the teachers had as much difficulties to proceed from their traditional view of learning to a constructivistic one as students have to proceed from their preconceptions to science conceptions. Further research on this is running in Leeds (s. Driver, 1986). Hopefully other research will follow.

This chapter set out to provide some insight in proposals for making science instruction more fruitful and more effective which are based on a constructivistic point of view and on research of students' conceptions. The state of research does not allow summarizing conclusions. Although at the moment more problems have been revealed than consequences successfully drawn, it not only appears to be promising but absolutely necessary to continue research in this area.

7. CONCLUDING REMARKS

Research in the area of students' conceptions started some 10 to 15 years ago with the investigation of students' conceptions in several science topics. It was deliberately reduced mainly to this cognitive aspect of learning. It met interests of psychologists involved in the "cognitive turn", i.e. involved in cognitive psychology. When research got under way and a further theoretical foundation was developed or adopted, it became clear that the problem of learning science cannot be reduced to this starting aspect. As the preceding chapters have pointed out, we have now returned to

the whole complexity of science teaching which we wanted to reduce at the outset. This is a great challenge to research in our field. On the one hand, taking the whole complexity into consideration is unavoidable, but on the other hand, research could lose its bearings in the labyrinth of this complexity.

There is another aspect of utmost importance for research in our field. So far there have only been rather limited attempts to carry our state of knowledge (i.e. our knowledge of students' conceptions in different areas of science as well as our teaching proposals) to the teachers. Considerable emphasis should be given such attempts. But there is a remarkable problem. Almost no empirical studies are available on the needs a teacher really feels. We do not know, for instance, whether teachers are already aware of the learning difficulties our research has revealed or whether we have to make them aware of it. Here too, research would be helpful.

8. REFERENCES

- Areh, C., Gunstone, R.: Teachers' concepts in science. *Research in Science Education* 15, 1985, 151-157
- Andersson, B.: The experiential gestalt of causation: a common core to pupils' preconceptions in science. *European Journal of Science Education* 8, 1986, 155-171
- Baird, J.R.: Improving learning through enhanced meta-cognition: a classroom study. *European Journal of Science Education* 8, 1986, 263-282
- Bereiter, C.: Toward a solution of the learning paradox. *Review of Educational Research* Vol. 55, no.2, summer 1985, 201-226
- Claxton, G.L.: Teaching and acquiring scientific knowledge. Centre for Science and Mathematics Education. Kings' College. University of London, n.d.
- Claxton, G.L.: The alternative conceptions' conceptions. *Studies in Science Education* 13, 1986, 123-130
- di Sessa, A.: Knowledge in pieces. Address to the 15th Annual Symposium of the J. Piaget Society. Philadelphia, June 1985

- Driver, R.: Reconstructing the science curriculum: the approach of the Children's Learning in Science Project. Paper prepared for the Annual Meeting of the AREA. San Francisco, 1986
- Driver, R., Easley, J.: Pupils and paradigms: a review of literature related to concept development in adolescent science students. *Studies in Science Education* 5, 1978, 61-84
- Driver, R., Erickson, G.: Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education* 10, 1983, 37-60
- Driver, R., Guesne, E., Tiberghien, A. (Ed.): *Children's ideas in science*. Milton Keynes, Philadelphia: Open University Press, 1985
- Driver, R., Oldham, V.: A constructivist approach to curriculum development in science. Paper prepared for the symposium "Personal Construction of Meaning in Educational Settings", BERA, Sheffield, 1985
- Feher, E., Rice, K.: Development of scientific concepts through the use of interactive exhibits in a museum. *American Museum of Natural History* 28, 1985, 35-46
- Feyerabend, P.: *Science in a free society*. London: New Left Books, 1978
- Fisher, K.M., Lipson, J.J.: Twenty questions about student errors. *Journal of Research in Science Teaching* 23, 1986, 783-803
- Gauld, C.: Models, meters and memory. *Research in Science Education*, 1986, 49-54
- Gentner, D., Stevens, A.L. (Ed.): *Mental models*. Hillsdale: Lawrence Erlbaum, 1983
- Gardner, P.L.: Students' interest in science and technology: an international overview. In: Lehrke, M., Hoffmann, L., Gardner, P.L.: *Interests in Science and Technology Education*. Kiel: IPN/UNESCO, 1985, 15-34
- Gilbert, J., Osborne, R.: Identifying science students' concepts: the interview about instances approach. Paper presented at: Cognitive Development Research Seminar, University of Leeds, 1979
- Gilbert, J., Osborne, R., Fensham, P.: Children's science and its consequences for teaching. *Science Education* 66, 1982, 623-633
- Gilbert, J., Watts, M.: Concepts, misconceptions and alternative conceptions: changing perspectives in science education. *Studies in Science Education* 10, 1983, 61 - 98
- Giordan, A.: *Bibliographie concernant les recherches sur les conceptions des apprenants en biologie*. Annales De Didactiques Des Sciences, no.2, 1987
- Glaserfeld, E.v.: Learning as a constructive activity. In: Bergeron, J.C., Nevscovis, N. (Ed.): *Proceedings of the 5th Annual Meeting of PME-NA*, Montreal, 1983
- Gunston, R., Northfield, D.J.: Learners-teachers-researchers: Consistency in implementing conceptual change. Paper presented at the meeting of the AERA. San Francisco, 1986
- Hanson, N.R.: *Patterns of discovery*. Cambridge: The University Press, 1965
- Hashweh, M.Z.: Toward an explanation of conceptual change. *European Journal of Science Education* 8, 1986, 229 - 249
- Hofstadter, D.R.: *Gödel, Escher, Bach: an eternal golden braid*. New York: Penguin, 1979
- Jung, W.: Fachdidaktische Aspekte des Kategorienproblems. In: Jung, W.: *Aufsätze zur Didaktik der Physik und Wissenschaftstheorie*. Frankfurt/Main: Diesterweg, 1979, 94-120
- Jung, W.: Uses of cognitive science to science education. Paper presented to the ATEE Symposium on the Implications of Cognitive Science for the Education of Science Teachers. Kiel, 1985
- Lakatos, I.: Falsification and the methodology of science research programs. In: Lakatos, Musgrave: *Criticism and the growth of knowledge*. Cambridge: The University Press, 1970, 91-195
- Karniloff - Smith, A., Inhelder, B.: If you want to go ahead, get a theory. *Cognition* 3, 1976, 195-212
- Kelly, G.A.: *The psychology of personal constructs*. Vol. 1,2. New York: W.W. Norton, 1955
- Klausmeier, J.H., Ghtala, E.S., Frayer, D.A.: *Conceptual learning and development: a cognitive view*. New York: Academic Press, 1974
- Klopfer, L.: Intelligent tutorial systems in science education: the coming generation of computer-based instructional programs. *Journal of Computers in Mathematics and Science Teaching* V, no.4, 1986, 16-32
- Korth, W., Cornbleth, C.: Science is ... mis/conceptions of prospective teachers. Paper presented at the Annual Meeting of the AERA. San Francisco, 1986
- Kuhn, T.S.: *The structure of scientific revolutions*. Chicago: University of Chicago Press, 1970
- Linn, M.: Learning more with computers as lab partners. University of California/Berkeley, 1986
- Magoon, A.J.: Constructivistic approaches in educational research. *Review of Educational Research* 47, 4, 1977, 651-693
- Maichle, U.: Representation of knowledge in basic electricity and its uses for problem solving. In: *Proceedings of the international workshop on "Problems Concerning Students' Representation of Physics and Chemistry Knowledge"*. Ludwigsburg, 1981, 174-193
- Marton, F.: Phenomenography - describing conceptions of the world around us. *Instructional Science* 10, 1981, 177-200
- Mitchell, J., Baird, J.: Teaching, learning and the curriculum I: The influence of content in science. *Research in Science Education* 16, 1986, 141-149

- Wachtigall, D.:** Vorstellungen im Bereich der Mechanik. In: Duit, R., Jung, W., Rhöneck, Ch.v. (Hrg.): Alltagsvorstellungen. Naturwissenschaften im Unterricht Physik/Chemie 34, April 1986, 16-20
- Niedderer, H.:** Probleme der Lebenswelt, Vorverständnis der Schüler und Wissenschaftstheorie als Determinante für den Physikunterricht. In: Fischler, H. (Hrg.): Lehren und Lernen im Physikunterricht. Köln: Aulis, 1982, 105-132
- Novak, J.D.:** Metalearning and metaknowledge strategies to help students learn how to learn. In: West, Pines (Ed.): Cognitive Structure and conceptual change. Orlando: Academic Press, 1985, 189-209
- Osborne, R., Freyberg, P.:** Learning in Science. The implications of children's science. Auckland: Heinemann, 1985
- Osborne, R., Wittrock, M.:** The generative learning model and its implications for science education. Studies in Science Education 12, 1985, 59-87
- Oser, F., Reich, K.H.:** Zur Entwicklung von Denken in Komplementarität. Berichte zur Erziehungswissenschaft. Pädagogisches Institut der Universität Freiburg (Schweiz). Nr. 53, 1986
- Pfundt, H., Duit, R.:** Bibliography: Students' alternative frameworks and science education (2nd ed.), 1987
- Pines, A.L., West, L.H.:** Conceptual understanding and science learning: an interpretation of research within a source-of-learning framework. Science Education 70, 1986, 583-604
- Pope, M.:** Constructivist goggles: implications for process in teaching and learning. Paper presented at BERA Conference Sheffield, 1985
- Posner, G.J., Strike, K.A., Hewson, P.W., Gertzog, W.A.:** Accomodation of a scientific conception: toward a theory of conceptual change. Science Education 66, 1982, 211-227
- Schecker, H.:** Das Schülervorverständnis zur Mechanik. Bremen: Universität Bremen, 1985
- Tasker, R., Freyberg, P.:** Facing the mismatch in the classroom. In: Osborne, Freyberg, 1985, 66-80
- Watts, D.M., Pope, M.:** Modulation and fragmentation: some cases from science education. Paper presented at the 6th International Congress on Personal Construct Psychology. Cambridge, 1985
- Watzlawick, P. (Ed.):** Die erfundene Wirklichkeit. München: Piper, 1981

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The philosophical preconceptions held by science teachers have aroused greater interest recently.¹ I can certainly confirm that such preconceptions do exist, and that epistemologically they are, in general, of an empiricist nature. But there is more. Although my purpose here is not to offer statistical data, it may be useful to preface the main subject of this paper by indicating briefly the general character of these preconceptions as they appear to me in the course of teaching philosophy of science to groups of in-service, high school science teachers in New York City.

Epistemological empiricism surfaces often in such remarks as this: "I believed that anything stated in a science text was a fact unless otherwise identified.... Theories had been taught to me as fact throughout high school, college, and graduate school." However, many teachers also evince a thoroughgoing ontological realism of two different kinds -- in regard to concepts and in regard to laws. That is, such constructs as inertial mass are assumed to be pre-existing and discovered; while in regard to laws, one often finds that these also are taken as pre-existing, discovered, and absolute. Thus, another teacher was very sceptical that "continuous creation of matter" (as it appears in "steady-state" cosmology) could possibly have been proposed by legitimate scientists, even if the amount "created" was below the threshold of detection. "It violates conservation of energy,"

she insisted. When it was pointed out that big bang theories are based on a similar, perhaps more drastic notion, this teacher confessed that, indeed, she had always had trouble understanding the big bang for the same reason -- which just shows that conservation may be even more difficult to unlearn than it is to learn.

Of course, among philosophers of science, realism (of a certain kind) is today a most praiseworthy stance; and I do not mention it here as a fault. What I wish to highlight is the unlimited and unreflected way in which it is often held by teachers -- certainly without awareness of alternatives or of the problems to which it may lead. Moreover, the viewpoints I have just described suggest that such preconceptions are not the result of any sort of consistent, though perhaps outdated, philosophy. What I see instead is an odd assortment of fragments: snatches of empiricism, isolated metaphysical principles, and generalizations representing varying degrees of "construction" -- all taken as fact, and held as core-concepts that exert influence on newly encountered knowledge. More systematic studies of all this would, I think, be very welcome at this point.

My object in this paper is two-fold: first to indicate what I believe is an important continuing reason for this problem of incoherent preconceptions; and then to outline one way, the way I have used, of confronting the problem through formal course-work with teachers.

Concerning the first point, and putting the conclusion before the evidence, I suggest that a major source of the teachers' and the public's "misunderstanding" of science is ourselves; that

is, scientists, textbook writers, popularizers, teachers of students, and teachers of teachers -- in short, most of the academic community. This thought will not be shocking to those working in the area of misconceptions, and so I will not belabor it. But to make sure we have before us a vivid image of what actually takes place today in the realm of philosophical-scientific education, let me give one especially worthwhile example. It is taken from writings that are deliberate attempts to explain to the educated public what science is like, among the best received such writings in our time, and the work of a well-known and acclaimed scientist -- Stephen J. Gould.

I quote first from a widely reprinted essay called "Evolution as Fact and Theory":

Facts are the world's data.

Theories are structures of ideas that explain and interpret facts.

Facts do not go away while

scientists debate rival theories for explaining them. Einstein's theory of gravitation replaced Newton's but apples did not suspend themselves in mid-air pending the outcome....

In science "fact" can only mean

"confirmed to such a degree that it

would be perverse to withhold provisional consent."²

Notice how thoroughly empiricist this is (as is the rest of this essay). Facts are first of all observational data, like falling apples. Later Gould includes also what he calls "confirmed" inferences from direct observation; but neither the observations nor the inferences are dependent on theory in any way. And so, we are told further on,

the inferences are "no less secure" than direct observation.

But now let me take an excerpt from another essay of Gould's,³ which actually appeared earlier; it is titled "Validation of Continental Drift":

I remember the a priori derision of my distinguished stratigraphy professor toward a visiting Australian drifter. He nearly orchestrated a chorus of Bronx cheers from a sycophantic crowd of loyal students.... Today, just ten years later, my own students would dismiss with even more derision anyone who denied the evident truth of continental drift.... During the period of nearly universal rejection, direct evidence for continental drift -- that is, the data gathered from rocks exposed on our continents -- was every bit as good as it is today. It was dismissed because no one had devised a mechanism that would permit continents to plow through an apparently solid oceanic floor. In the absence of a plausible mechanism, the idea of continental drift was rejected as absurd. The data that seemed to support it could always be explained away (emphasis added).

Continuing the story, Gould tells us that with some new data and a heavy dose of "creative imagination," we have now fashioned a new theory of planetary dynamics:

Under this theory of plate tectonics, continental drift is an inescapable consequence. The old data from continental rocks, once soundly rejected, have been exhumed and exalted as conclusive proof of drift. In short, we now accept continental drift because it is the expectation of a new orthodoxy (emphasis added).

The rest of the article describes some of this data that was previously rejected but later exhumed and reinterpreted. Finally, toward the end, Gould spells out the lesson: "The new orthodoxy colors our vision of all data; there are no 'pure facts' in our complex world (emphasis added)."

In viewing these two essays side by side, we ought to note the element of consistency as well as the obvious divergence of meaning. In both cases the "facts" did not "go away." But, it turns out, there are different senses of the phrase "to go away." In the first essay, Gould-the-positivist drives home the major point about the givenness of facts, their rootedness in the nature of things, by pointing triumphantly to the unimpeachable assertion that no one has yet seen an apple fall up from a tree. In the second essay, Gould-the-Kuhnian shows by means of some dramatic recent history precisely how, in a different sense, facts can indeed "go away" -- not by nature changing its ways, not necessarily by the discovery of error in the process of observation, but also when facts are "explained away", or ignored, or simply "dismissed" as not sufficiently significant.

When writing about evolution, Gould is what Hilary Putnam calls an "externalist" -- facts are

external to theory. But in regard to continental drift, he is an "internalist" -- the facts, if not completely constituted by theory are, in a way, coaxed by the theory, and given their meaning and significance by theory. My point here is not that Gould has to be wrong somewhere (though I will return to this matter) but that, like many other scientists, on philosophical questions he is just plain careless; and carelessness of this sort, even when practiced with a most engaging style, can only leave confusion in its wake -- incoherence. This example, I think, when taken with much other evidence of the same sort, tends to place in a different light the oft-repeated complaint about the public's "misunderstanding" of science. At least in regard to such things as "fact" and "theory," or comprehension of structures of ideas as wholes, or the capacity to gauge meaning, it is probably as much a problem of misteaching as misunderstanding.

But why the misteaching? Well, as we know, scientists normally feel that the ground they stand on is their professional, technical achievement, not their more general, philosophical commitments. What we see here is the divergence of two different interests: The interest of education, even in science, is not entirely the same as the interest of the associated professional community or the discipline. The interest of the discipline may at times countenance not just philosophical carelessness but even a degree of philosophical opportunism. On the other hand, the interest of education includes (as we often say) conveying a coherent picture of what science is like. If this is accepted, then serious attention to philosophy

of science becomes, for all levels of teaching, an obvious desideratum.

Assuming this much as a goal, I now shift abruptly to the second task of this paper -- the description of an implementation designed for in-service teachers, that bases itself on the primacy of the historical viewpoint over the analytical. I take the scientific-philosophical education of the teacher as an end in itself, without regard to how that education may be used in the teacher's own work. In defense of this, I offer two considerations: 1) that the teacher corps in an open society is, from an intellectual point of view, a significant sector of that society, whose opinions on science and culture are important as such, and not merely as means toward more successful teaching of subjects; 2) that even when our aim is to use philosophy of science to improve the teaching of science itself, it is still undesirable, if not inconceivable, that teachers employ and transmit the insights of scholarship without themselves consciously absorbing these very insights. Therefore, in what follows, I make no suggestion that the method described, or any part of it, can be directly applied by teachers in their own classrooms.

The approach is based on the following features:

- 1) A graphical scheme representing the structure of scientific fields -- an adaptation of William Whewell's "induction tables" -- applicable (within limits) regardless of specific philosophy.
- 2) Discussion of particular scientific theories, including their technical aspects.

- 3) Application to scientific or social or educational controversies.

While the last two features are by no means secondary, the remaining discussion is devoted mainly to the first -- because much of what I want to say about the other two can be said in that context, along the way. And toward the end, I will return to the more general implications.

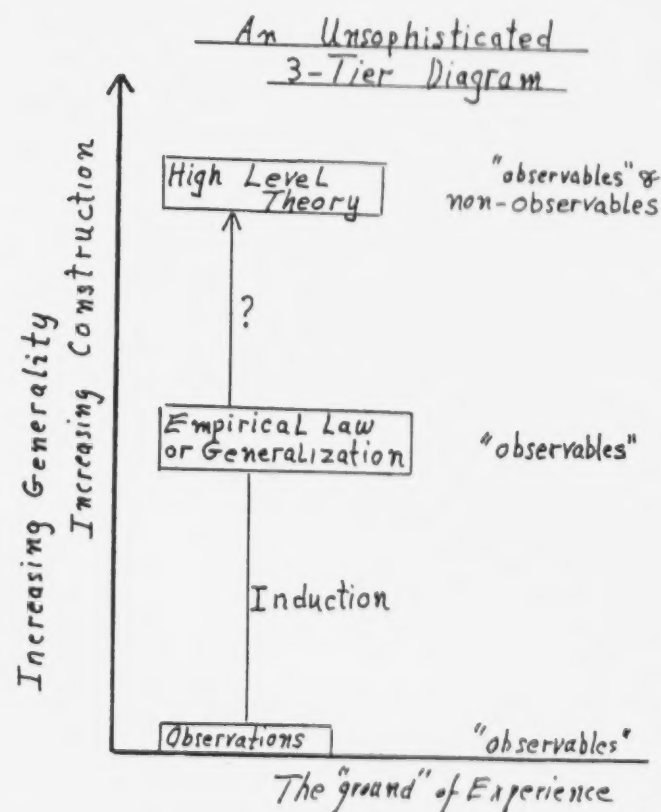


fig. 1.

We start with a very unsophisticated "3-tier" diagram of a scientific field or sub-field (fig. 1). Although we know that the distinction between empirical and theoretical laws is not sharp or universally recognized, and neither is the separation of "observables" from "non-observables," nevertheless, in the educational context I regard such objections as of second order. For those who think this so oversimplified that it has little value, let us recall first that the basic terminology of the scheme is widely used in science textbooks on the college level, and that this specific hierarchy has been implicit in the writings of philosophers from William Whewell to Nagel.⁴ So it is something relatively familiar. Second, precisely because it is crude, it is not this picture that occasions major differences between the modern philosophies; we can use it in discussing positions that range from extreme empiricism to at least a moderate constructivism. Third, and most important, we only begin with this diagram. Later, other features are added, and it does, of course, get more complex.

I have found that even this crude scheme, when thoroughly discussed and illustrated, already introduces an important change into people's views. For many, it alters the landscape of science from one of flatness -- all real science is fact -- or from a hierarchy based only on degree of confirmation -- fact, theory, hypothesis, speculation -- to one where there is some depth (in several dimensions).

However, the only way to really teach this is to move quickly to a number of well-known exemplars: In physical chemistry, with Boyle's law at the middle level, the kinetic theory is high

level. In cosmology, with Hubble's law in the middle, the big bang theory is at the top (fig. 2). In mechanics, if Kepler's ellipses and Galileo's law of falling bodies are at the intermediate level, Newtonian theory, at the apex, unifies these two disciplines, as the textbooks say (fig. 3).

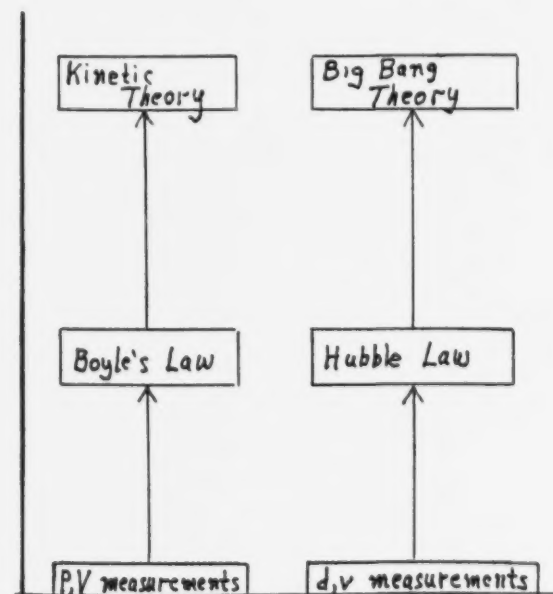


fig. 2

Many features of science can now be discussed by reference to these diagrams, with suitable illustrations from the exemplar cases. The lower upward arrow often, but not always, stands for relatively unproblematic induction -- like extrapolation and interpolation. The movement of historical development is generally (but not always) upward. The direction of explanation, and deduction, is typically downward. And a major

difference between the higher levels and the realm of merely empirical laws is that the former characteristically introduce concepts, and processes, that are not directly observable, sometimes even in principle unobservable -- though it should be noted that Nagel, for example, declined to make this the demarcation criterion between experimental and theoretical laws.

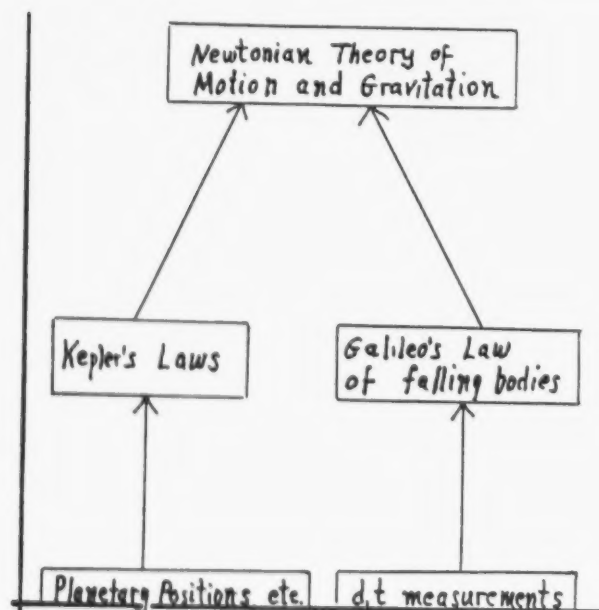


fig. 3

Obviously it is possible to draw such diagrams for segments of optics, geology, electromagnetism, and many other fields. And in doing so one is led to deal with scientific disciplines wholesale, and in a comparative way -- often a new and dizzy experience for those narrowly trained. This, of course, cannot be done without assuming, or

imparting to the students, a certain amount of knowledge, including historical knowledge, of some of these fields. It is at this point that my second feature -- dealing with science itself -- comes in, and does indeed take up at least 50% of the time.

One benefit is that students of certain sciences, like biology, where the distinction between empirical and theoretical law is not often so clear, have a chance to refocus on a field like physics, where it is far more prominent. Hugh Helm has pointed out that many beginning students do not recognize the difference between definitional, or tautological, laws and laws of nature.⁵ To this I can add that many high school science teachers do not recognize even obvious differences between experimental and theoretical laws, or between induction and deduction, and have trouble with other distinctions of the more abstract kind. This simply tells us that misconception or preconception, whose origin may sometimes be profound, are mixed also with plain ignorance, especially in regard to general concepts concerning science as a structure of ideas.

But now the point: After some work with the three-tier diagrams, most students begin to see that the situation cannot be as simple as that. Should Boyle's Law and Keplerian orbits really be at the same level? The former seems to fit well the Baconian prescription -- collect data, and discover patterns. But it is surely debatable whether "seeing" the elliptical orbit in the data of planetary positions is at all in the same category. In fact, this was the subject of the famous 19th century debate between William Whewell and John Stuart Mill, with Whewell arguing for what we now call the more constructivist position.

Historically speaking, there were real choices in moving from the ground of observation to what, from our present vantage point, is the intermediate level; and for this, a separate 3-tier diagram can be drawn. With diurnal motions, planetary positions, etc., at the bottom level, there were three different candidates at the highest level: the Ptolemaic system, the heliocentric, and Tycho Brahe's compromise system. Between observations and the major "world systems," we would place the empirical generalizations accepted at the time -- maximum elongations of the inner planets, the retrograde motions, etc. From this point of view, and our present hindsight, all candidate systems are imaginative constructs. Therefore, the first change in the "unsophisticated" diagram is to allow for bands, or many levels, instead of just three tiers (fig. 4). Elliptical orbits and Boyle's Law might still be somewhere in the middle band, but with the former higher than the latter.

The need for other kinds of corrections, or refinements, is even more glaring. The ground level of the cosmology diagram contains such "observations" as distances and speeds of galaxies. But since these are not in fact directly observed -- another point calling for scientific discussion prior to the philosophical -- some structure must be introduced here as well, to account for background theories. And so, depending on how far one wishes to probe, the diagrams can indeed become very cluttered. The heuristic point to all this is not so much in "getting it right" -- although, within bounds, that must of course be the goal -- but in the discussions one is forced to go through in deciding where to place a particular element.

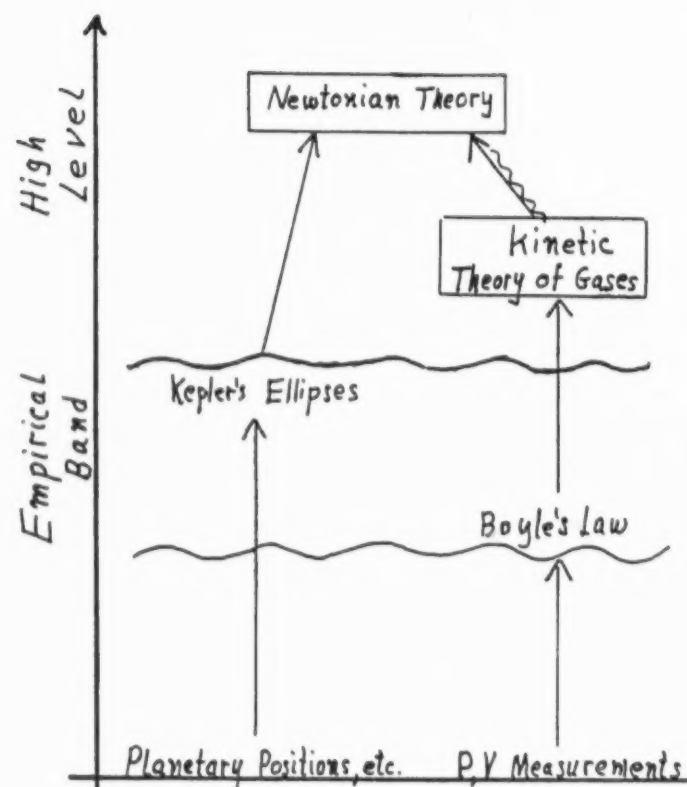


fig. 4

We have to consider what its relation is to other elements, what sort of concepts it involves, which is the direction of deduction, what its historical development was, and so on. Clearly this is an exercise, a critical exercise -- an exercise in a particular kind of concept mapping, which shares therefore many of the virtues and shortcomings that are already known in regard to such exercises.⁶ But in contrast to some other kinds of mapping, the basic format and principles here are clearly laid

down at the start, and are taken from the historical-co-philosophical disciplines relating to science. It should therefore be no surprise that such diagrams are a very old thing; in a somewhat different form, William Whewell called them "induction tables." He drew up large, complicated ones, paying particular attention to history, and took them very seriously not only as a means of understanding science, but even as a way to -- "truth."⁷

Let me turn now to philosophies as such. The diagrams certainly do not depict everything; we cannot, for example, show any difference between realist and instrumentalist viewpoints (usually discussed in such a course), for that would require some portion of the diagram to refer to "reality" -- and locating "reality" on this plane is not easy. But let me point out those things the diagrams can do. It may seem at first that the very structure of this scheme -- everything proceeding from the "ground" of experience, and the resemblance to Whewell's thinking -- already has built into it a philosophical bias. Perhaps, but if so, the bias can be overcome. We do start with a number of variants of positivism (which, by the way, is certainly not dead); but then we go on to the Popperian viewpoint, and to the Kuhnian version of what is now called "the new philosophy of science."

The typical positivist concern, simply put, was to verify, or make secure, the valid inductions represented by the upward trend in these diagrams, and to screen out those inductions which could not be so secured. Whewell's way of doing that -- what he called the "consilience of inductions" (and what we might call convergence) was simply that the more

upward arrows converging on the same high level theory, the better. So if to the two inductions of fig. 3 we add orbits of comets, satellite orbits around Jupiter, tides, the oblateness of the earth, and much more, we then have the paradigmatic case of consilience (fig. 5). And on a diagram such converging arrows do look impressive.⁸

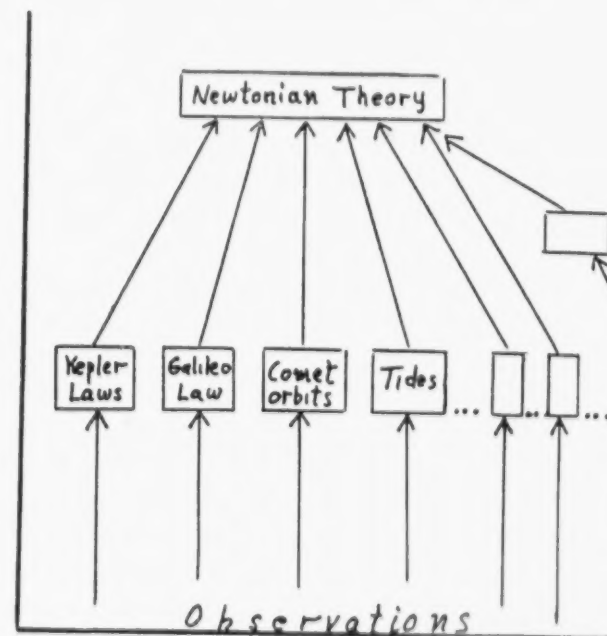


fig. 5

An alternative method was to concentrate on quality rather than quantity. Thus, the approach of positivism in our century was to examine meticulously each upward arrow and develop, whenever possible, special procedures to make that arrow more solid, more reliable. Examples of this would be operationalism, the quest for a pure

observation language, and so on. On a diagram, we might just draw a thicker arrow to indicate security.

Finally, among the positivists we had also the famous radical branch which included Ernst Mach. For them the problem was that regardless of the number of arrows, or how secure they are, high level theory usually contains constructed concepts not accessible to direct measurement -- which might well be fictions. Their bold solution, doing away with high level theories, or at least some of them, means that the top tier is simply crossed off.

When we get to Karl Popper the discussion becomes particularly interesting. On the one hand, Popper liked to emphasize his difference from the positivism of his time, but on the other, some philosophers have continued to include him within that general designation. Let us see how, on these diagrams, both the differences and the similarities appear.

The main distinction, of which he is so proud, consists in the now-famous characterization of the upper arrow as a "conjecture," a guess. Inspired by Einstein, and the difficulties inherent in contemporary versions of the positivist program, Popper concluded that "induction is a myth."⁹ One way of indicating this graphically is to replace the solid arrow by a broken (dashed) arrow -- conjecture replaces inference.

But Popper's resemblance to positivism can be seen in his partial return to the consilience of inductions. Quality and quantity are both emphasized by him, couched in new terminology and a different interpretation, and presented as an improved version of the hypothetico-deductive method: The conjecture must give rise to "interest-

ing," "risky," or "improbable" deductions -- denote this by wiggly lines to the lower levels -- which, if corroborated, yield what in the older language would have been inductive support. The risky deduction, whenever successful, elicits a solid upward arrow, which is no longer just a conjecture (fig. 6).

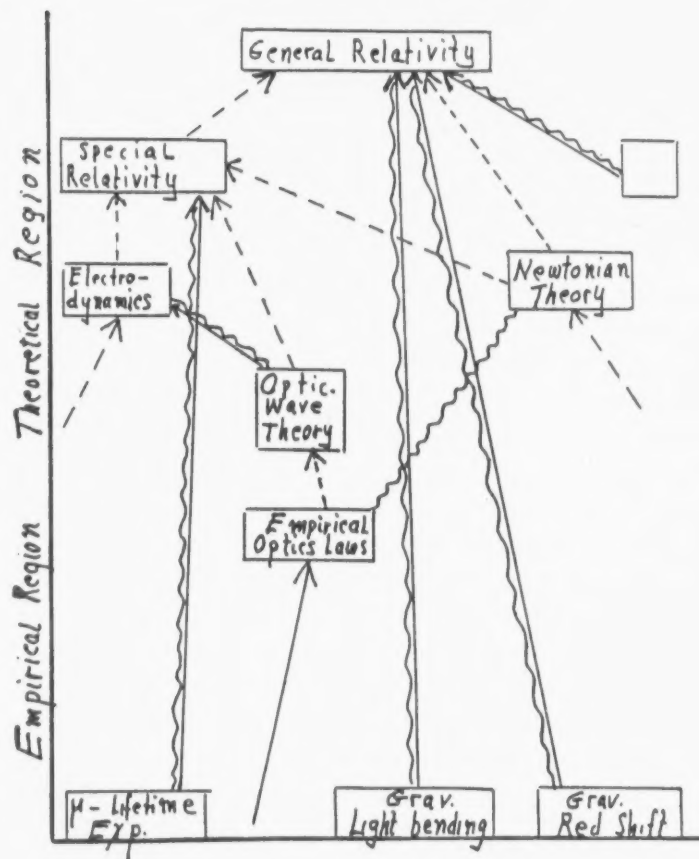


fig. 6

The resulting picture looks very much like the old consilience, with the following changes: First, the new analysis relies much more on corroborations after the initial conjecture than on the historical path -- we call this the dominance of the context of justification over the context of discovery -- and second, the corroborations that really count must be of a certain kind.

It is important to emphasize at this point that such a use of diagrams, in themselves, or as part of a purely analytical discussion, would only add to mystification. Although there may be other influences, the various philosophies are strongly related to events in science itself. Twentieth century positivism cannot be understood without some idea of the rise -- in the late 19th and early 20th century -- of new sciences and concepts outside the Newtonian framework, and of the resulting collapse (as ultimate explanation) of the best-corroborated high level theory in all history. Nor can current Popperian and Kuhnian themes really be understood except as a response to the 20th century revolution in physics. For this reason, a historical account of scientific change, utilizing the more recent works in this area,¹⁰ is, I believe, the best way to attempt this sort of teaching with any group of people who, for the most part, are not philosophically inclined.

As a final illustration of the use of the diagrams, consider now Kuhn's well known reaction to both positivism and the Popperian viewpoint. Graphically, this is indicated by a series of thick, looping arrows downward from the higher levels (fig. 7). These represent not only the "theory-ladenness" of observation, but also the effect of theory on methods, on standards, on

problem choices, etc. It is important to distinguish sharply these downward arrows from any kind of deductive inference in the hypothetico-deductive procedure. (Here a degree of graphical consistency is called for.) Deductions lead typically to particular testable observations, which either pass or do not pass the test. To distinguish these verbally from the Kuhnian feedback loops, I use for the latter the term "reverse induction" or "downward induction." In this way, I mean to highlight the generalizing nature of such feedback.

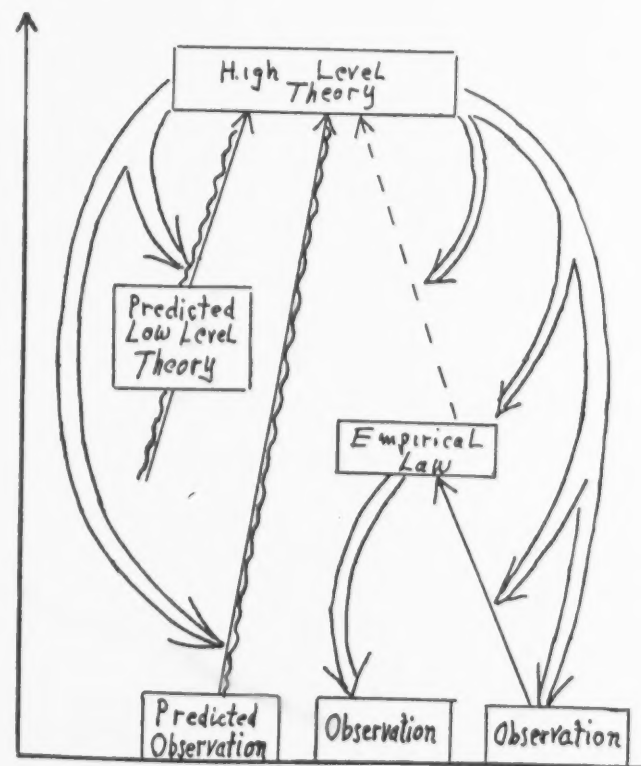


fig. 7

Consider Gould's example. Before plate tectonics, no observation could support continental drift because such drift was "known" to be impossible. That is a very general kind of downward inference concerning evidence. One result of the success of the special theory of relativity was to legitimate operationalism in quantum theory. That is a very general influence on procedures in research. And, of course, the hypothetico-deductive method itself acquired its articulated and acknowledged status largely as a result of the success of Newtonian theory.

The new picture -- which, as a whole, can be called a Kuhnian "paradigm" -- now has the kind of look that does seem to reflect our verbal descriptions. The feedback loops make it more dialectical, more self-contained, and more like what we today call constructivist. Naturally, this does not take the place of reading Einstein, Bridgman, Nagel, Popper, Kuhn, Toulmin, and others; in the end, the diagrams must become merely symbolic or mnemonic aids.

However, in regard to the value of using alternative philosophies of science, I should like to make one comment a propos of a paper by Joseph Nussbaum.¹¹ He pointed out, in the context of research on students' conceptual change, that there are significant differences between the post-Kuhnian philosophies, and that these differences must be taken into account. Everything I have said so far surely supports the value of attention to philosophical differences and alternatives; but when it comes to teaching itself (as distinguished from research) I should like here to raise a flag of caution. I am sceptical that such differences as exist, for example between Kuhn and Lakatos, can provide any fruitful lessons. After much discus-

sion, Kuhn thought that "Lakatos' position is now very close to my own."¹² And Feysabend called Lakatos' philosophy an "anarchism in disguise."¹³ Even the protagonists do not agree on many of their differences. My experience has been that it is a very demanding task just to convey clearly the significance of the distinctions between the main branches -- that is, classic positivism, Popper, Kuhnian constructivism, and the ontological schools -- even when the students are mature adults, teachers of science, diligently trying to improve their grasp of the issues. For that reason I prefer to take one or two representatives of each school, keep the diagrams as simple as possible, and concentrate on the relation between the philosophy and science itself.

But a fair question to ask at this point is what sort of results are we to expect from such studies, beyond the general feeling that the widening of horizons is good for everyone. In partial reply, let me return to Gould's writings and to the role of controversies in this approach.

In the essay, "Evolution as Fact and Theory," Gould's aim is to convince readers that evolution is both fact and theory, and that those who now emphasize the word "theory" are improperly, deviously attempting to cast doubt. Gould's response, and that of many others, is to separate the basic proposition (Darwin's "descent with modification") from the question of specific mechanisms -- and, speaking in his positivist mode, to pin the label "fact" on the basic proposition. This argument is now very familiar, and it all but indicts -- for ignorance or worse offenses -- anyone who fails to treat the basic proposition as "fact."

But after weeks of using these diagrams in a comparative manner, and having seen family resemblances between laws and theories across disciplinary lines, it becomes possible for some to view the fact/theory controversy in alternative ways -- ways which often reflect a deeper grasp of the process of science, and at the same time a deeper insight into alternative modes of education.

As an example, consider this: William Whewell also regarded a complex, indirectly established proposition as both fact and theory; but he was referring to something quite different from Gould's (in this case) more positivistic dissection: "All attempts," says Whewell, "to frame an argument by the exclusive or emphatic appropriation of the term fact to particular cases, are necessarily illusory or inconclusive."¹⁴ Why? The answer, in his work, received special emphasis:

The distinction of fact and theory is only relative. Events and phenomena considered as particulars which may be colligated [i.e., subsumed] by induction, are facts; considered as generalities already obtained by colligation of other facts [i.e., induction from them], they are theories. The same event or phenomenon is a fact or a theory, according as it is considered as standing on one side or the other of the inductive bracket [on our diagram, the arrow].¹⁵

Although here we are listening to a voice from the 19th century, which on many other points is now

outdated, the above statement was actually ahead of its time, and is not likely to raise opposition from many philosophers of science today -- since modern examples of what he is saying are easy to find. When, all over the world, calculations are carried out for atomic phenomena, quantum effects are of course taken for granted -- treated as facts. But when Aspect and his collaborators performed their celebrated experiments in 1982 (using Bell's theorem), quantum mechanics was in the full sense a theory, pitted against other possible theories (hidden variables).¹⁶ In other words, it all depends on what the goal of the inquiry is.

But it is in education that the implications of this last point have the greatest scope; for education often has a number of distinct goals. If the aim is to train people in an existing scientific paradigm, then everything that is at present well established is "fact." If, on the other hand, the goal is to understand inquiry more generally, and the significance of the different kinds of products of inquiry, then it follows just as surely -- whether we are looking at relativity, or at the basic proposition of evolution, or at Newton's laws, or at anything else -- that inductions or conjectures (upward and downward), not just the paradigmatic deductions, ought to be at the center of attention. And then all these major achievements of science are indeed "theories" about which one can argue.

From this perspective, and aside from the very different import of the two Gould essays I mentioned, it is possible to see that even the first essay (the positivistic one), taken alone, suffers from certain limitations. By insisting on

"the fact of evolution," it merely describes the existing state of affairs in biology as a research discipline. When used to correct misconceptions or misleading statements about that discipline, this argument is perfectly in order. But in the wider context of education, it is important to realize that how much priority we give to imparting information about the state of the discipline is a goal-dependent judgment, a judgment of philosophy of education, a pedagogical judgment, sometimes a social or legal judgment, but not a matter for authoritative scientific decision.

I have found that the discussion of controversy, such as the current one on creation/evolution, the 19th century debates on the same issue, the ones on sociobiology and on the computer model of mind -- all of which involve science and more general human concerns -- have the advantage of simultaneously putting the various schematizations to use, and of testing them. Therefore, if this approach brings an otherwise abstract and "academic" discipline -- philosophy of science -- to life, to intellectual use, this is by no means of secondary value.

American teachers, for example, receive from state education departments various guidelines on how to teach evolution. They also receive in their mailboxes literature from a number of outside organizations, questioning evolution or the manner of teaching evolution, and attempting to involve these teachers actively in the controversy.¹⁷ Aside from other good arguments for the serious study of the philosophy of science, it does seem that teachers ought to have more adequate intellectual tools for coping with such real-life problems.

NOTES AND REFERENCES

1. Joseph D. Novak, "Can Metalearning and Meta-knowledge Strategies To Help Students Learn How to Learn Serve as a Basis For Overcoming Misconceptions?" Misconceptions in Science and Mathematics (Proceedings of the International Seminar, June 20-22, 1983), Hugh Helm and Joseph D. Novak eds., (Ithaca: Cornell University, 1983).
2. Stephen J. Gould, Hen's Teeth and Horse's Toes (New York: W.W. Norton, 1983) pp. 253-262.
3. Stephen J. Gould, Ever Since Darwin (New York: W.W. Norton, 1977) pp. 160-167.
4. Ernest Nagel, The Structure of Science (Indianapolis, IN: Hackett, 1979), ch. 5.
5. Hugh Helm, "Do Students Understand The Nature and Role of Scientific Concepts?" in Misconceptions in Science and Mathematics (note 1).
6. Joseph P. Novak and D. Bob Gowin. Learning How to Learn (Cambridge: Cambridge U. Press, 1984).
7. Robert E. Butts, ed., William Whewell's Theory of Scientific Method (Pittsburgh: U. of Pittsburgh Press, 1968) p. 20.
8. It should be noted, though, that Whewell actually used brackets instead of arrows, to emphasize the generalizing and subsuming aspects of science.
9. Karl R. Popper, Conjectures and Refutations (New York: Harper & Row, 1963), p.53.
10. The key work in the historico-philosophic school is still Thomas Kuhn's The Structure of Scientific Revolutions, 2nd ed. (Chicago: Univ. of Chicago Press, 1970). But useful also are Imre Lakatos and Alan Musgrave eds., Criticism and the Growth of Knowledge (Cambridge: Cam-

- bridge Univ. Press, 1970); Steven Brush, "Should History of Science Be Rated X?", Science 183 (1974), pp. 1164-1172. On history of evolution, there are, among many others: Neil C. Gillespie, Charles Darwin and the Problem of Creation (Chicago: Univ. of Chicago Press, 1979); David L. Hull, Darwin and His Critics (Chicago: Univ. of Chicago Press, 1973). For representative statements of the "constructivist" position in the sociology of science, we have Barry Barnes, Scientific Knowledge and Sociological Theory (London: Routledge & Kegan Paul, 1974); Barry Barnes and David Bloor, "Relativism, Rationalism, and the Sociology of Knowledge" in Martin Hollis and Steven Lukes eds., Rationality and Relativism (Cambridge, MA: The MIT Press, 1982).
11. Joseph Nussbaum, "Classroom Conceptual Change: The Lesson to be Learned From The History of Science." in Misconceptions in Science and Mathematics (note 1).
 12. Thomas Kuhn, "Replies to Critics," in Criticism and the Growth of Knowledge (note 10) p. 239.
 13. Paul Feyerabend, Against Method (London: Thetford Press, 1975) p. 181.
 14. William Whewell's Theory of Scientific Method, p. 275.
 15. Ibid. p. 161.
 16. Fritz Rohrlich, "Facing Quantum Mechanical Reality," Science, 221 (23 September, 1983) pp. 1251-1255.
 17. One of the more scientifically resposible in this category is Teaching Science in a Climate of Controversy (Ipswich MA: The American Scientific Affiliation, 1986).

DISTINGUISHING STUDENT MISCONCEPTIONS
FROM ALTERNATE CONCEPTUAL FRAMEWORKS
THROUGH THE CONSTRUCTION
OF CONCEPT MAPS

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I have taught General College Chemistry at a two-year college for sixteen years. For the past six years, I have used the concept mapping technique with my students in an attempt to overcome the compartmentalized, weakly related manner in which textbooks present the chemistry subject matter and to actively involve my students in their learning process.

The method I have developed places the emphasis on student constructed concept maps. At the beginning of the semester, I distribute a set of guidelines for constructing concept maps and one simple example of a concept map. I spend one lecture discussing the method, purpose and value to the student of their developing conceptual relationships and seeing unity in chemistry. I assign concept maps of each chapter of the textbook to be constructed by the students. In the last third of the semester I have them relate the subject matter of two or more chapters.

The principal reason for my using this method is to improve student learning and I have found that (1) students become active participants in their learning; (2) students learn as they construct their maps; and (3) students form a unified picture of chemical concepts. However, I also unexpectedly found the student constructed maps were powerful tools for evaluating a student's understanding.

The evaluation of student understanding from concept maps has two principal components. First, I found it identified students alternate frameworks of understanding

of a given subject area, and second, I found it allowed me to identify misconceptions held by a student.

Regarding the first component, I found:

(1) every student's concept map of a given subject was different and individual even though each was substantially correct. If shared meaning has occurred between the teacher and student, the student has developed his own structure of knowledge and has incorporated the objective information into his own understanding;

(2) the student's map shows his overall picture of the subject area and the relative importance he has assigned to different conceptual areas; and

(3) the student's map identifies omitted areas in his understanding of the subject area.

Regarding the misconceptions component of the evaluation, I found:

(1) misconceptions are not merely an alternate way of seeing things. They are errors that will lead to conflicts if not corrected;

(2) misconceptions are always localized and specific;

(3) they are one incorrect relationship between two concepts;

(4) misconceptions can exist in an otherwise satisfactory framework; and

(5) misconceptions can be easily identified by the teacher and corrected in a short interview with the student.

I will present examples of each type of information available from the student constructed maps. First, however, I have found that, before the maps can be used for evaluation, the student needs to have acquired concept mapping skills and have confidence he is able to represent his personal understanding. He needs to overcome the master map syndrome in which he feels there is one correct map someplace that his map will be measured against. I found these prerequisites are only in place after students have

constructed five or six concept maps, and the teacher has discussed the student's maps with him in an interview. This usually occurs around mid-semester but will vary from class to class and student to student.

STUDENT ALTERNATE FRAMEWORKS

To illustrate students alternate frameworks, I have chosen concept maps of the gaseous state constructed by four students in the same lecture section and submitted during the tenth week of class. Each student's map is different and represents an alternate view of the gaseous state.

The first map, Figure 1, is by a student who had a difficult time constructing concept maps prior to this one. It was the first map that had a two dimensional structure. The concepts he maps are fairly clearly related. However, his map is only of the ideal gas law and he omits many concepts, especially those dealing with the kinetic molecular theory. He told me later that there were just too many ideas to put in one map.

The second map, Figure 2, is more complete and includes every concept given in the textbook. The student sees the gas laws, deriving from experimental measurements, as the central and overriding subject area. He relates the laws to the kinetic theory of gases but does not specify the relationship or relate the individual postulates of the theory to the gas laws. Thus, he indicates he has an inadequate understanding of the theoretical explanation of the gas laws.

The third map, Figure 3, is balanced and clear. The student sees the kinetic/molecular theory of gases as the principal overriding concept and relates the theoretical postulates to experimental evidence. His relationships bring the experimental laws together to form the ideal and real gas laws. He sees the laws as dependent on theory for their meaning.

NOTE: COPIES OF FIGURES SHOWING DETAIL ARE AVAILABLE FROM THE AUTHOR

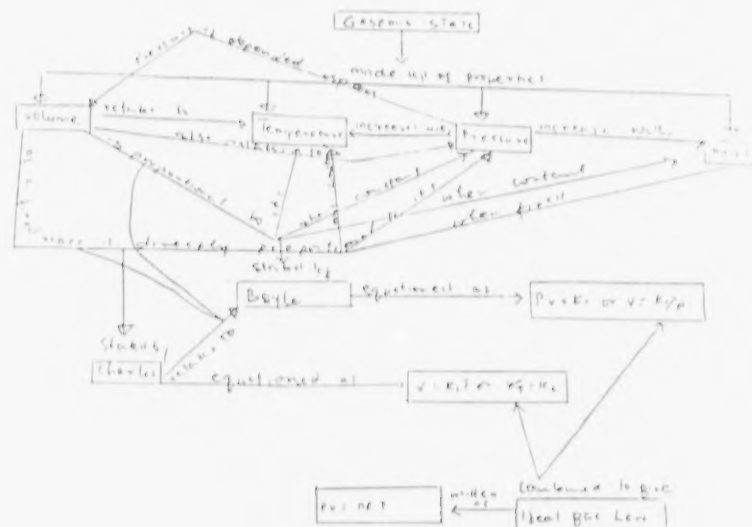


Figure 1

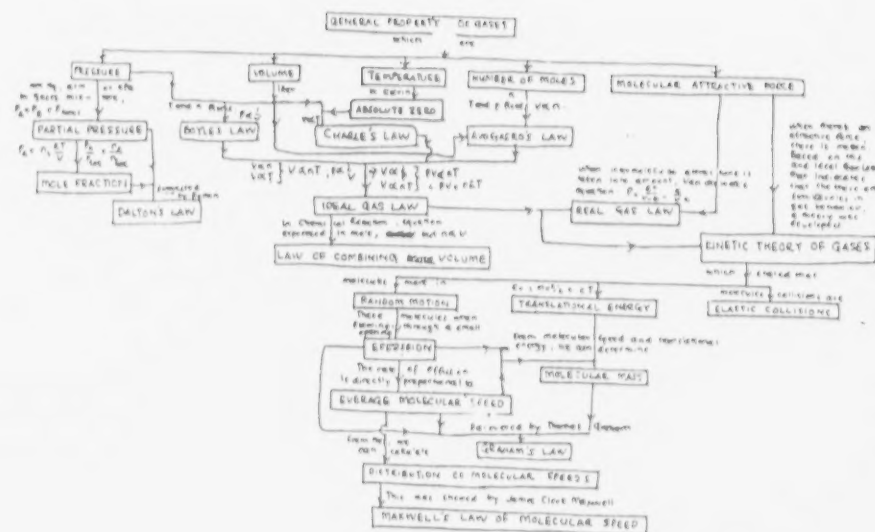


Figure 2

The fourth map, Figure 4, was 11" x 17", and much larger than any of the other students. This student sees the gaseous state in relation to the other two physical states. He also sees the laws and theory of the gaseous state as the side-by-side, equally important components which answer the "what" and "why" of gaseous behavior. He also sees the relationship between each variable of the ideal gas law and the postulates of the kinetic molecular theory.

Each of the last three students have a substantially correct understanding of the gaseous state and would do very similar work on any other evaluation tool. Their concept maps reveal they have significantly different understandings of the overall subject area of the gaseous state and the relative importance of each sub-area; especially the relationships between the gas laws and the kinetic molecular theory.

STUDENT MISCONCEPTIONS

To illustrate the ability of the student constructed maps to identify misconceptions for the teacher, I will show two students' misconceptions of the same relationship that I found in concept maps that were otherwise conceptually correct. The erroneous relationship by each student is between "intermolecular forces" and "kinetic energy of molecules" and yet each is very different.

The first example of a misconception was found in the student's concept map of the gaseous state above (Figure 2). The upper right hand corner, expanded in Figure 5, shows a relationship between "molecular attractive forces" and "kinetic theory of gases". The student states "where there's an attractive force, there is motion" thus indicating a casual relationship between molecular attractive forces and molecular kinetic energy which is erroneous and would make it impossible for the student to see the role of intermolecular forces in understanding the condensed states of matter. This one relationship identified two

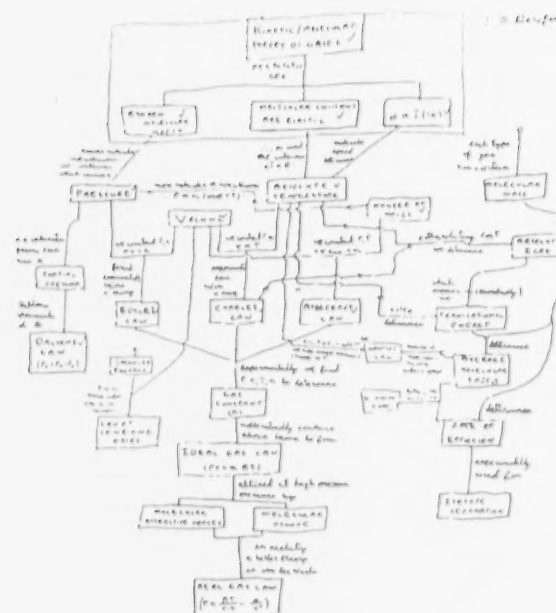


Figure 3

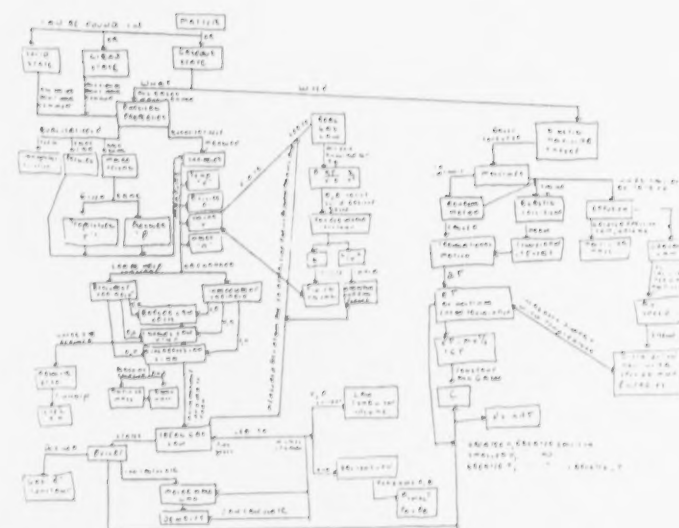


Figure 4

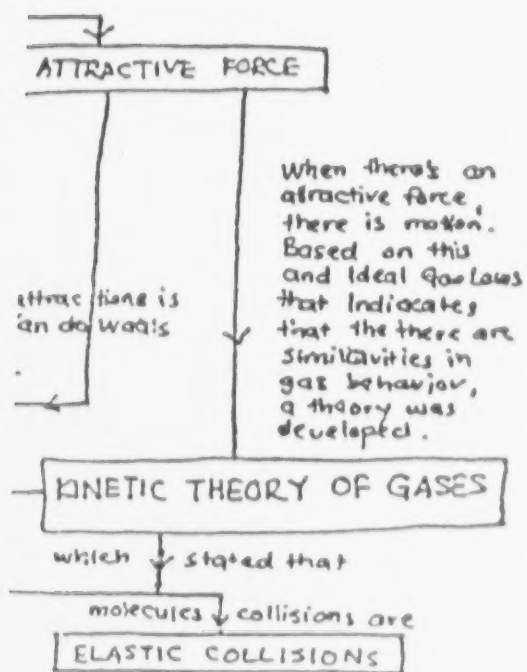


Figure 5

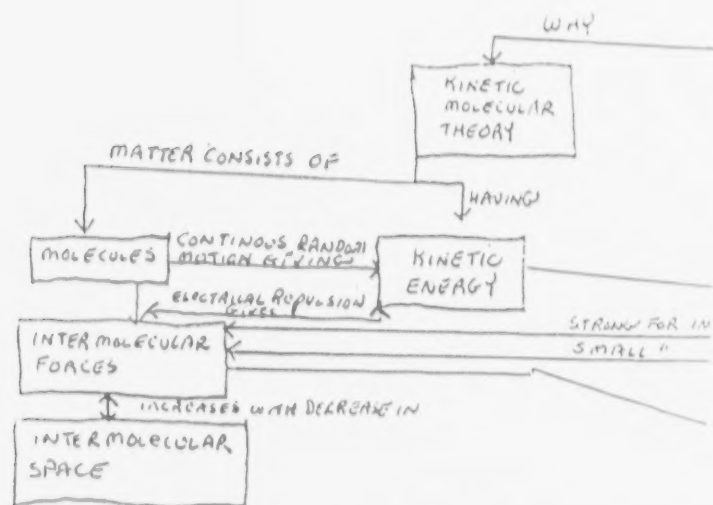


Figure 6

major misunderstandings, first, that molecular motion is caused by intermolecular forces, and second, the stronger the intermolecular forces the greater the molecular motion. Once I identified this important, but localized, misconception from the student's map, it required approximately five minutes of discussion with the student to correct his misunderstanding and develop a correct understanding. The student's new understanding was verified with his next concept map of the liquid and solid state.

The second example of a misconception was by the student who constructed Figure 4 above of the gaseous state. His next map was of the condensed states and in the lower left corner under "kinetic molecular theory" he also showed a casual relationship between "intermolecular forces" and "molecular kinetic energy", Figure 6. The major difference is that he saw intermolecular forces as forces of repulsion. This one relationship, similar to the first example, identified two major misunderstandings, first, that molecular motion is caused by intermolecular forces and second, very different than the first student, that intermolecular forces were forces of electrical repulsion. This one mistaken relationship would make it difficult for the student to understand the forces involved when a substance changes state. Again, once I identified this major misunderstanding from the student's map, I was able to correct, in a short conversation, the student's misunderstandings.

I feel the student constructed concept maps allowed me to identify and correct major misconceptions by these two students, misconceptions that would have been difficult to ascertain using other methods of evaluation.

CONCLUSION

I have found student constructed concept maps to be powerful evaluation tools that identify both student alternate frameworks of understanding and student misconceptions. Regarding alternate frameworks, they show:

1) Each student's personal knowledge is different and he comes to this by developing his framework of conceptual relationships.

2) Concept mapping is a powerful tool for a student to develop his understanding and express his understanding.

3) Concept maps of a given subject area by students can be substantially correct and yet significantly different structures revealing major differences in student's understanding.

4) Concept maps identify areas of possible omission in a student's understanding.

Regarding misconceptions, they show:

1) Student misconceptions are specific, local relationships between two concepts.

2) Misconceptions can exist within an overall conceptual framework which is satisfactory.

3) Misconceptions are easily corrected and frequently change the meaning of the entire conceptual framework.

4) The more specifically a relationship is named, the more readily it can be identified as correct or incorrect.

I have taught chemistry for six years using student constructed concept maps and I feel my students are now actively involved in their learning and are gaining a more balanced, personal understanding of chemistry. Further, I, as a teacher, feel that the subject matter I taught is the subject matter that was learned and a sharing of meaning has occurred.

Using Hierarchical Concept/Proposition Maps
to Plan Instruction that Addresses Existing and
Potential Student Misunderstandings in Science

by Thaddeus W. Fowler and Saouma Bou Jaoude
University of Cincinnati

In order to help teachers develop instructional plans that address student misunderstandings, a planning technique has been devised where teachers construct and use concept/proposition maps (unit maps) to lay out what is to be taught and to identify possible areas of misunderstanding by students. The maps are organized around categorical concept hierarchies and cover the content of a microschema or unit. On the maps are diagrammed facts, concepts, propositions, attitudes, science processes, and physical skills to be taught during the presentation of a unit of instruction. The information is diagrammed in a way which shows the interrelationships among the content. Once the content of the unit has been mapped, the information is reviewed in each of the areas of knowledge to locate potential misunderstandings on the part of students prior to or during the teaching-learning process.

According to Gagne (1987), there are five major learned human capabilities. These are: verbal information, intellectual skills, cognitive strategies, attitudes, and motor skills. Verbal information can be further categorized (Gagne, 1970; Eggen, Kauchak, & Harder, 1979; Ausubel, Novak, & Hanesian, 1978) into stimulus-response learning (facts), categorical concepts, and rules (propositions, generalizations or principles). As an information processor, the learner is clearly able to form concepts and propositions in addition to actively pursuing the acquisition of facts (Eggen, Kauchak, & Harder, 1979).

Although having a large store of accurate knowledge is a prerequisite for successful learning and problem solving, the

structure in which this knowledge is stored is also important. According to Reif (1983) and Resnick (1983), most students have a store of knowledge that is small, not well organized and full of well established misconceptions, while the knowledge base available to successful learners and problem solvers is large and well organized (Eylon & Reif, 1979; Frederiksen, 1984; Smith & Good, 1984; Stewart, 1982a, 1982b, 1983).

There are numerous techniques that can be used to help learners organize their knowledge store. Knowledge vee Diagrams, advance organizers, lesson outlines, and concept maps are a few of these techniques. Concept mapping has been shown to be a powerful and successful technique when used in instruction (Eylon & Reif, 1979; Novak, Gowin, & Johansen, 1983; Stewart, 1983). The quality of student knowledge is improved when concept mapping can be used to identify and correct student misconceptions. Students, as well as teachers, can be trained to use concept maps to organize their own knowledge.

As part of the instructional planning process, teachers should reflect on the possible misunderstandings their students might possess. Instruction needs to build on the foundational knowledge of students. Teachers should consider the prior degree of understanding of the topic to be taught and work to expand and refine the cognitive structures of students. However, unless teachers consider the misunderstandings held by students, instruction might be overwhelmed by these misunderstandings. Unless misunderstandings are directly addressed, students may be so confused or 'hung up' that they are not able to pay attention to the new content being taught. Students may think that they already know the topic and the new material makes no sense, they may become frustrated because of apparently conflicting information, or new content might not fit with

personal foundational knowledge that is predicated on misunderstandings.

As a way of being better able to identify possible misunderstandings it is helpful to categorize them into types paralleling the domains of knowledge. By classifying the misunderstandings, insight can also be gained into ways of addressing or correcting the inaccurate knowledge. For example a misunderstanding about a categorical concept might be addressed by explicitly using a nonexample of the concept which 'short circuits' the misunderstanding or causes the student to appropriately limit the range of the concept.

Here in consideration of the different types of misunderstandings and in the unit maps, knowledge is categorized into the cognitive, affective, and psychomotor domains. The cognitive domain is further divided into the areas of singular facts, categorical concepts, propositions (generalizations or principles), and science processes (intellectual skills). The affective domain is addressed through the identification of attitudes (composed of feelings, beliefs, and actions). Physical skills fall within the psychomotor domain.

Within the cognitive domain knowledge is carefully partitioned to fulfill the following definitions. Facts are defined as content which is singular in occurrence and acquired solely through the observation of events, occurring in the past or present (Eggen, Kauchak, & Harder, 1979). Concepts are abstractions made up of the criterial attributes that a given category of objects, events, or phenomena have in common (Ausubel, Novak, & Hanesian, 1978). Propositions (principles) are formed by chaining two or more concepts (Gagne, 1970) or are a meaningful relational combination of two or more concepts, yielding a new idea (Ausubel, Novak, & Hanesian, 1978). Relationships between concepts that are

only hierarchical are not considered here to be propositions. Intellectual skills are any of the well recognized science processes that are used to collect, organize, and manipulate data, or create new knowledge.

Categorization of misunderstandings done according to different types of knowledge yields the following system.

Misfact - memorized factual knowledge which is wrong

Avogadro's number is 6.023×10^{25} .

The side of the Moon not facing Earth never receives direct sunlight.

Misconception - inaccurate understanding of a concept, misuse of a concept name, wrong classification of concept examples, confusion between different concepts, improper hierarchical relationships, over- or under-generalizing of a concept

Frogs are reptiles.

The eight planets and the Earth rotate around the sun.

The Earth revolves on its axis.

Vertebrates are a kind of mammal.

Mass and weight are the same thing.

Seals are a kind of fish.

Misproposition - wrong or inaccurate propositions, improper application of propositions, merging of two or more propositions, over- or under-generalizing of a proposition

The heavier an object is the faster it falls.

Charles' Law is used to determine the new volume of a balloon as it is moved from the surface of a lake to 30 feet below the surface, assuming the thermocline to be at 40 feet.

A student decides that the reaction between sodium and fluorine gives off less heat per mole than the reaction between sodium and iodine.

Tissues are made up of organs.

Metals are a type (or category) of element.

Misbelief - a cognitive misunderstanding which leads to a consequential attitude

Snakes are cold and slimy.

Scientists seldom make mistakes.

The bible is precisely accurate.

Mismanipulation - physical manipulations done improperly or ineffectually

Pictures taken of a nonmoving object with a Polaroid camera are in focus, but blurred.

A student punctures the palm of the hand while inserting a thermometer in a rubber stopper.

Processing mistake - inaccurate or illogical thought processes such as classifying mistakes, improper interpreting of data, failing to control variables; the misuse of any of the science processes (characterized by Piagetian cognitive task mistakes)

As a student investigates the factors that influence the growth of plants, the amount of water applied and the amount of sunlight allowed are varied simultaneously.

A student counts the legs on an ant and gets eight.

A student determines that there is no relationship between the length of time a force is applied to an object and the velocity of the object, since each time the experiment is done slightly different results are obtained.

In order to facilitate the recognition and identification of possible misunderstandings, as well as to aid a teacher in more easily perceiving the complexity, interconnectedness, and extensiveness of the content to be taught, unit maps are developed and used. Unit maps graphically present a cognitive structure of a microschema of content and include facts, concepts, propositions, science processes, physical

skills, and attitudes. The directions for the production of a unit map follow.

The purpose of this exercise is for you to practice the use of a method of planning and analysis of a quantity of instructional content. You will focus on a unit of instruction. A unit is typically a single chapter in a text or a few closely related short chapters and where the instruction will typically last for about two weeks. During the exercise you will list pertinent facts, concepts, and propositions your students would be expected to learn as well as science processes to be developed, attitudes to be formed or preserved, and physical skills to be developed. Further, you will graphically show the interrelationships among these entities.

1. Obtain a sheet of 17 x 22 in. or 24 x 36 in. paper and two or three fine tipped colored marking pens.
2. List the concept names included in the chapter (toward the center of the paper) in strict categorical hierarchies. It is probably best to also include concepts that are closely related to this unit but which appear in previous and following chapters. You will typically end up with three to ten hierarchies.
3. List facts (at the bottom of the paper) included in the unit that are so important that students would be expected to commit them to memory. Concept definitions would of course not be listed.
4. Connect two or more concepts with a line to show a mutual relationship in the form of a proposition. Do this for each important proposition in the unit. Lines connecting higher order (more abstract) concepts form higher order propositions.
5. List propositions (down the right side of the paper) as complete statements and in an outline format to show their hierarchical relationships and label the corresponding lines connecting related concepts.
6. List the science processes you wish to develop (at the upper left of the paper) coding these processes to the cognitive information to be learned in conjunction with the processes. (Use colored dots.)
8. List physical skills to be developed (at the middle left of the paper), coding to cognitive information.
7. List the attitudes you wish to form or preserve (at the lower left of the paper).

Once this comprehensive listing of content has been diagrammed instructional objectives can be written, possible misunderstandings can be identified for each of the content areas of the map, resources identified, instructional activities devised, and assessment instruments produced. Of most importance, the planning and delivery of instruction is more likely to proceed in an integrated and meaningful manner. This is probably especially true for teachers who have produced their own maps rather than those using a map drawn by someone else.

Instruction might proceed according to any of a number of instructional models. Deductive model, inductive model, and Ausubel model lessons (Eggen, Kauchak, & Harder, 1979) can be designed drawing from the concept and proposition hierarchies displayed on the map. Instruction seems to proceed best when examples are used to clearly illustrate and delineate concept categories (Joyce & Weil, 1980) and to illustrate propositions. Misconceptions and mispropositions can be counteracted, curtailed, or prevented during the instructional process through the judicious use of examples and nonexamples when illustrating concepts and propositions.

Examples are chosen from the mapped concept or proposition hierarchies from subordinate levels. Since the map graphically displays subordinate levels, a full and valid range of examples can be more easily and accurately chosen. Nonexamples might typically be drawn from coordinate categories and delimit the range of a concept category or the applicability of a proposition. Deductive lessons proceed downward through the hierarchies from a statement of a concept definition or a proposition through examples taken from subordinate levels. Inductive lessons proceed upward with the presentation of examples or illustrations and with students developing concept definitions or statements of propositions which are superordinate to the examples.

Ausubel model lessons present the content of entire concept or proposition hierarchies first downward (progressive differentiation) and then roughly upward (integrative reconciliation).

Teachers report that this planning technique is very powerful, exhaustive, and helpful and also extremely time consuming. The method has been used for about three years with undergraduate students, experienced inservice teachers, and with corporate trainers. Almost all teachers and teachers in training initially experience considerable difficulty in conceptualizing the task before them. Much of their distress is related to the task of discriminating between the different types of knowledge, especially facts, concepts, and propositions. Once a map has been produced, the elegance of a variety of instructional models is immediately apparent to teachers. The execution of the planning and delivery of instruction seems to be considerably enhanced. Most teachers spontaneously express their delight in gaining new insights into the interrelatedness of the content they teach. Furthermore, teachers seem to be much more attuned to the misunderstandings that might exist or occur in the variety of knowledge areas.

- Eggen, P., Kauchak, D., & Harder, R. (1979). Strategies for teachers. Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Eylon, B., & Reif, F. (1979). Effects of internal knowledge organization on task performance. San Francisco, CA: University of California, Berkeley. (ERIC Document Reproduction Services NO 171 804).
- Frederiksen, N. (1984). Implications of cognitive theory for instruction in problem solving. Review of Educational Research, 54.(3), 363-407.
- Gagne, R. (1970). The conditions of learning (2nd ed.). New York: Holt, Rinehart and Winston.
- Gagne, R. (1974). Essentials of learning for instruction. Hinsdale, IL: The Dryden Press.
- Gagne, R. (1987). Instructional technology: foundations. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Joyce, B., & Weil, M. (1980). Models of teaching (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.
- Novak, J., Gowin, D., & Johansen, B. (1983). The use of concept mapping and knowledge vee diagrams with junior high science students. Science Education, 67(5), 625-645.
- Reif, F. (1983). How can chemists teach problem solving? Journal of Chemical Education, 60(11), 948-953.
- Resnick, L.B. (1983). Mathematics and science learning: A new conception. Science, 220(4595), 477-478.
- Smith, M., & Good, R. (1984). Problem solving and classical genetics: Successful versus unsuccessful performance. Journal of Research in Science Teaching, 21(9), 895-912.
- Stewart, J. (1982a). Difficulties experienced by high school students when learning basic Mendelian genetics. American Biology Teacher, 44(2), 90-94.
- Stewart, J. (1982b). Two aspects of meaningful problem solving. Science Education, 66(5), 731-749.
- Stewart, J. (1983). Students' problem solving in high school genetics. Science Education, 67(4), 523-540.

CONCEPT MAPS AS REFLECTORS OF CONCEPTUAL UNDERSTANDING

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INTRODUCTION

Over the past ten years science education research in Australia and New Zealand has focussed attention on student misconceptions in science. Such researchers as Gunstone and White (1980) and Osborne and Gilbert (1979) have revealed some of the misconceptions that students acquire during their schooling. Revelations such as these have helped to emphasise the need for teachers to be aware of what conceptions and misconceptions their students bring into instructional settings.

In reviewing what educational psychology had revealed about the facilitation of pupil learning Lovell (1980) concluded:

First I believe that, in general, what the pupil knows today, what relevant anchorage he has, is the best single predictor of what he will know tomorrow as a result of your teaching ... Second, it is necessary for the teacher to try and establish the main ideas held by pupils at the time they begin to experience new material. Pupils hold many spontaneous strategies, misconceptions, and alternative frameworks ... Teaching must be adjusted to the anchorage the pupil already holds. At times interpretations of the pupil must be compared and contrasted with those of the teacher. Teachers can use individual interviews and concept mapping to establish ideas held.

Teachers roll their eyes in disbelief at the suggestion of a regular regime of individual interviews. The restructuring required to enable such a system to operate is massive and unlikely to be widely implemented in classrooms. Concept mapping, on the other hand, offers a technique for revealing cognitive structure which appears manageable within present classroom constraints. This paper reports on part of a pilot study which investigated the feasibility of using concept mapping in secondary science classrooms.

SETTING AND DESIGN

The study involved instruction in concept mapping for twenty-four grade nine science students in a small co-educational independent school in North Queensland. The students were drawn from two classes totalling sixty-three students. The sample students chosen were low and medium achievers as revealed by classroom tests. They normally worked in pairs and these same pairs were used throughout the study. During each of three month-long work units, groups of four students were put through the following treatment:

Step 1: The four students were each given a list of approximately ten central concepts associated with the coming unit of work. They were asked to write down all they knew about these concepts, under exam conditions with no time limit.

Step 2: Individual audio-taped thirty minute interviews were held within one to three days of the examination. The focus of each interview is to reveal the students' understanding of these same concepts.

Step 3: A thirty-minute training program in concept mapping, done separately with each pair of students out of class time.

Step 4: Construction of concept maps during class and homework time over the four weeks of the unit. Individual on-going remediation was a part of this process.

Step 5: At the end of the unit each student constructed a concept map of the overall unit using a set of self-generated major concepts. This was done in their own time with no time limit.

Step 6: Individual audio-taped interviews were held within one to three days of this task. The focus of each interview was to reveal the student's understanding of the concepts discussed in Steps 5 and 1. Student attitudes towards concept mapping and its effect on their learning were also sought.

The procedure for training in concept mapping (Step 3) was as follows:

- (i) Illustration of the key characteristics of a concept map using diagrams familiar to the students: a food web and a classification key (Fraser, 1983, p.53-58),
- (ii) comparison of a concept map and the written paragraph from which it was developed (Novak, 1980, p.ii-8 and p.ii-9),
- (iii) provision of a format for constructing a concept map,
- (iv) individual student production (using the given format) of a concept map based on a hobby or interest, and
- (v) remediation and discussion of the map.

Two basic formats for map construction (Step iii) were tried:

Format 1

- (a) Write down six or seven key words associated with the hobby,

- (b) order these words from most to least important (two or more words can be of equal importance),
- (c) form the words into a map with the most important words at the top and the least important at the bottom, and
- (d) draw lines between words which can be related to each other and write linking words on the lines.

Format 2 was an adaptation of Format 1 based on a procedure suggested by Fensham, Garrard, and West (1981). Here Step (b), the ordering of words, was accomplished by a mathematical procedure. The degree of relation between each pair of words is rated on a 0-3 scale and by summing the relational ratings a total rating is achieved for each word.

RESULTS AND DISCUSSION

Comparison of written and verbal responses

A comparison of student's written reports and associated interviews prior to training in concept mapping (Steps 1 and 2) generated three major findings. Firstly, there were significant inconsistencies between what students had written about the ten concepts and what they revealed subsequently during interview. Responses were classified into five categories correct, incorrect, ambiguous incomplete, and no information. An inconsistency involved a shift from one category to another. Fifteen percent of the students showed inconsistency with only one concept, fifty percent with two to four concepts, and thirty five percent with five to eight concepts. The majority of the inconsistencies involved a shift from a partial, unclear or incomplete written response to a verbal response which was clearly correct or incorrect. Over seventy-five percent of the students revealed at least one clear contradiction between their written and verbal responses.

Secondly, neither concept difficulty nor student achievement level was related to the level or type of inconsistency for students in this study. Thirdly, ten percent of the interviewer's interpretations of the students' written responses were subsequently shown to be inaccurate by the interviews.

The major implication from the comparison is that the written responses were not clear indicators of cognitive structure. Students in this study had difficulty in accurately representing their conceptual knowledge in written form. As there was no time pressure, it appears that lack of application and/or lack of fluency in written expression are likely explanations for the results obtained. This problem is compounded by the difficulty in accurately interpreting written responses. Results here suggest that not only do many students have problems with the encoding (expressing their ideas clearly in written form), but also teachers can have trouble with the decoding (accurately interpreting what is written). Take, for example, a written statement on 'formula' by one of the students: "An amount of substances put together".

From this a teacher could easily assume that the student had at least a vague notion of formula as representing "substances" joined together in some way and even some sense of proportions or amounts. However during interview the student showed clearly that he had confused formula with equation. On re reading the written statement in light of the interview, one gets a very different understanding of what was intended.

In summary, if one is to attempt to base one's instruction on what the students already know, as Lovell suggests, it appears that sole reliance on written

reports of the type used here would be unwise.

Different methods for teaching concept mapping

All of the students acquired concept mapping skills to a sufficient degree to allow them to draw competent maps. At the same time, a number of the students showed little enthusiasm for the process. It was seen as being a lot of extra work which they would happily avoid. All students trained with Format 2, the mathematical calculation, complained about the tedium of the process. A number of them were at pains to point out how they could order the concepts in much simpler ways. No such complaints emerged from the group trained with Format 1. The maps produced by the two formats revealed no significant differences. The extreme unwillingness of students to work with Format 2 suggests that for these grade nine students at least, Format 1 is the better procedure to use in the classroom setting.

Comparison of concept maps and interviews

Interviewing is widely accepted as a method for revealing cognitive structure. The enormous influence of Piaget and his Geneva co-workers, based on his "clinical method" of interviewing (Opper, 1974) is convincing evidence of this. The interview techniques used here were based on Opper's discussion of the Piagetian clinical method (Opper, 1974) and the adaptation of the clinical method to concept mapping used by Novak and his Cornell group (Pines et al., 1978).

Table 1 shows the number of propositions each student included in the concept map prepared in Step 5, at the end of the unit. A proposition is here defined as "a specific relationship between two or more concepts" (Novak, 1980, p.203). It should be noted that some of these

TABLE 1

Propositions Revealed by Concept Maps and by Interviews

Student	Number of propositions in map	Percentage spontaneously revealed in interview	Percentage subsequently revealed by probing
K.G.	19	74%	26%
A.N.	17	82%	18%
B.P.	15	87%	13%
L.G.	15	80%	20%
S.G.	15	80%	20%
H.R.	15	73%	7%
S.E.	14	64%	29%
G.M.	13	77%	23%
A.Re	12	100%	-
M.R.	12	83%	17%
P.W.	12	83%	17%
C.V.	10	80%	20%
I.M.	10	50%	-
K.M.	9	78%	22%
S.S.	8	100%	-
N.M.	7	100%	-
K.R.	7	100%	-
J.W.	7	100%	-
A.R.	7	86%	14%
I.F.	7	86%	14%
C.B.	7	86%	14%
K.H.	6	100%	-
P.M.	5	100%	-
C.B.	5	80%	20%

propositions were in fact misconceptions. The Table also shows the percentage of these propositions which were revealed during the subsequent interview (Step 6) - firstly those revealed spontaneously, and secondly those revealed by subsequent probing. The interview was held at least one day after the map was prepared, and up to three days after. Also, no reference was made to the concept map by the interviewer. The degree of agreement between the propositions revealed by the students' maps and the subsequent interviews is impressive. In only three cases, H.R., S.E. and I.M. did students not reveal all of their map propositions after probing during interview. The one student who could reveal only 50% of her map propositions, and 'gave up' when probed presented an interesting case. Only five of her ten propositions were correct and four of these were revealed during interview. Even when cued she could reveal only one of her five misconceptions. It appeared that these may have been guesses which were put in to 'pad out' the concept map.

While most students were able to elaborate slightly on propositions in their maps during interview, in only three cases did students reveal significant new information during interview. When questioned about this, one said that he didn't have the space to fit everything in his map, the second had included the information on her 'rough copy' of the map but had forgotten to put it into her 'neat copy' and the third suggested: "Just didn't think at the time to put it in". In all other cases if propositions central to the topic were not included in the concept map they were not subsequently revealed by the student when interviewed.

These results indicate that in this study concept maps were as accurate as interviews for revealing student

comprehension of concepts. The implications of this finding for classroom practice are powerful. Many researchers, for example Lovell (1980), have long advocated the individual interview as the best way to access student understanding. If a more comprehensive study confirmed the results obtained here, it would provide teachers with a very convenient, time-efficient indicator of student understanding for classroom use.

This contrast between the high equivalence of information revealed by concept maps and interviews, and the low equivalence between information revealed by written answers and interviews is worthy of comment. This finding implies that concept mapping significantly helps students to clearly express their comprehension of concepts and conceptual inter-relationships, as well as helping the teacher to understand the written student communication. This implication can only be seen as tentative since the comparison of written and verbal answers took place at the start of the topic when students would have been much less knowledgeable and much less confident on the topic.

Student and Teacher Reactions to Concept Mapping

Most students regarded concept mapping as hard work and as an extra imposition, particularly as many of their peers did not have to do it. At the same time, most felt that it helped their learning. For example:

"There's the hard part of working it out, but then you have it for reference - you can just look back for study."

"If you're a poor reader like me the map is good because it's easier to read".

"If you just study with words and writing out paragraphs they seem to just tell you about one thing, but if you're doing it in concept maps

you can link it up - you can join it all together with the rest of the subject. It explains that one subject part more thoroughly to help it join in with the others."

This function of helping students pull the topic together and develop a feeling of mastery was commented on by both the students and the teacher. Similarly the development of increased student self-direction was noted by the teacher as well as the students. For example:

"That's happened to me a couple of times - where I didn't understand what the words were where I should have, and I'd look it up in the book and be able to fit it in properly."

"First I see which ones [concepts] go together and the ones left over I look up and find out that they do go with others once I know their meaning."

While concept mapping helped make students aware of gaps in their understanding, the degree to which they took steps to remedy this varied greatly.

The teacher also commented on: the increased "academic self-concepts" of some students; the clarity with which the maps reveal student strengths and weaknesses; and the deeper level of processing encouraged by concept mapping. Marton and Säljö (1976) report that techniques which encourage deep level processing result in higher levels of outcome. The extent to which concept mapping coerces deep level processing is an important area for further research.

CONCLUDING COMMENT

Results from this pilot study suggest that concept mapping has great potential as a classroom procedure for revealing the conceptual understanding of students. It was shown to be as accurate as interviewing for this purpose. Added to this it seemed to have a number of positive effects on student learning.

REFERENCES

- FENSHAM, P.J., GERRARD, J., and WEST, L. A comparative critique of several methods of collecting data for cognitive mapping, Research in Science Education, Volume 12, 1982.
- FRASER, K. Concept mapping in the secondary science classroom Unpublished Honours Thesis, James Cook University 1983.
- GUNSTONE, R.F. and WHITE, R.I. A matter of gravity Research in Science Education, 10, 35-44, 1980.
- LOVELL, K. 'Siren voices and the facilitation of pupil learning' Unpublished paper James Cook University, 1980.
- MARTON, F. and SÄLJÖ R. On qualitative differences in learning, British Journal of Educational Psychology, 46, 4-11 and 115-127, 1976.
- NOVAK, J.D. Handbook for the Learning How to Learn Program Cornell University Press, Ithaca, U.S.A., 1980.
- OPPER, S., 'Piaget's clinical method - description and applications', Unpublished paper, University Sains Malaysia, 1974.
- OSBORNE, R.J. and GILBERT, J.K. Investigating students' understanding of basic physics concepts using an interview about-instances approach, Research in Science Education 9, 85-93, 1979.
- PINES, A.L., NOVAK, J.D. POSNER, G.J., and VAN KIRK, J. The Clinical Interview: A Method for Evaluating Cognitive Structure, Curriculum Series Research Report, Department of Education, Cornell University, Ithaca, U.S.A., 1978.

STUDENT USE OF COMPUTERS TO SELF-EVALUATE DATA FROM INTRODUCTORY PHYSICS LABORATORIES

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As more information about student conceptions of knowledge presumably acquired through a classroom experience is accumulated through research, there is a concomitant concern for ways of improving instruction related to that knowledge. A favored way of improving instruction is through expanding the number of presentations of the same subject. In the case of physics instruction, inclusion of laboratory work has traditionally been cited as the place where students have another opportunity to study or more directly observe some phenomenon described in text or lecture. Though not clearly supported by research, one can logically conclude that students experiencing laboratory work of both more appropriate quality and quantity will have fewer misconceptions about related phenomena than will those who have not; one goal of this paper is to present examples of expanded laboratory experiences.

Another pedagogical consideration addressed in this paper relates to the popular conception that students need to achieve some reasonable level of computer literacy through their standard course work. Undoubtedly, "Computer Literacy" has become a holy grail of the eighties; both the educational and computer journals are devoting more space to personal accounts describing micro-computer applications to educational problems. The entire May, 1987 issue of the The Physics Teacher is given over to this matter and The American Physical Society has begun a new journal (Fall, 1987) devoted to computers in the physics laboratory - both in research and education.

Specifically, this paper centers about the use of computers as a pedagogical device directed at improving the quality of laboratory experiences. One example allows the student to check the validity of laboratory data both with respect to accepted results and with the findings of other students. Another example will be directed at students' self-checks of calculations from their own data.

The Process of Learning Physics:

We know precious little about how people learn anything - physics included. In spite of the fact that we have had a number of cognitive scientists present us with models of human information processing, and we have had a number of researchers present data on both how the "successors" succeed and the current learning system "fails", there is little consensus among educators on appropriate learning prescriptions for success.

Few physics instructors would disagree with the premise that they would like to accomplish two main goals with their course. One goal being that the student is able to articulate some physics "knowledge" (e.g., a net force on a body produces an acceleration equal to the quotient of the force and the mass) and the other goal being that the student becomes aware of when it is appropriate to apply a particular piece of "physics knowledge".

Instructors prepare lectures which include several "clever" demonstrations and derivations; they plan labs which either provide personal encounters with classical events or "state-of-the-art" technology.

Yet the data provided in Fredette and Lochhead(1980), Clement(1979), Fredette and Clement(1981), Fredette(1981), and Steinberg (1984), to name a few, suggests a need for curriculum planners to rethink the foundations upon which their courses are built. The data described in these papers suggest that students make serious errors when asked to apply physics knowledge in some supposedly simple problems; we read of errors which we teachers would hardly expect our students to make - given the excellent instruction they receive. The truth of the matter is that if any of us closely examine the work of our "good", "non-major" students, we will find similar errors occurring in a similar incidence.

In Riley(1983), one finds the report of a study where instructional methods with respect to the learning of

physics were examined. Specifically, the Riley paper describes several investigations in which instructional models based on a fundamentally Gestalt cognition theory were tested. As in most educational research projects, the results have not been earth-shaking but the researcher is encouraged and feels the study worth pursuing.

The specific computer application being suggested here is partly in response to a conviction that learning is most effective when there is a sense of context for the learner; this is consistent with the cognitive development model of Piaget as well as the "Whole-Parts Schema" described by Riley. It is also partly in response to a sense that college students in the year 1987 ought to have a personal encounter with this particular technological device. These two major concerns have been translated into the development of a computer application which has the potential of enhancing the learning of physics.

The author of this paper, on the basis of 20 years as a college physics professor acting as the instructor in every aspect of the introductory physics course, has come to believe that independent student laboratory work (both physical and mental) is the area most in need of strengthening. This experience has shown that many students view the laboratory experience as an entity unto itself. The people being referred to here come to gather a specific collection of numbers as efficiently as possible; there seems little concern over the possibility that the data is either inappropriate or incomplete. Furthermore, previously cited research indicates that many perceive no connection between the data gathered in the laboratory and other aspects of the course. Data from a variety of sources (Larkin and Reif(1978) is one) does suggest that students do not readily create larger knowledge structures without environmental cues that it is appropriate to do so. The algorithm to be described, in the form of a computer program, has been designed with these learning precepts in mind.

The optimum solution is obvious: create a student sense of personal responsibility for solving a problem or answering a question yet provide some sort of as-needed structure and assistance. The operating environment must require that the student take an active role in deciding what to do next as well as allow for "professional" urging or help. In the proposed plan, it is suggested that the instructor withhold some of the detail of the experiment procedure; whatever parts it is felt will produce ambiguous, yet not completely disastrous results. Students must have enough of a sense they are on the right track toward completing the required work.

As part of his work in lab, the student is required to develop a tentative (or "final") answer to the problem being worked on.

The computer becomes an "advisor" whose level of subtlety in its degree of interaction with students will be a consistent one. The best-written computer-instruction sets have a high degree of "intelligence" when it comes to individualizing the level of subtlety.

The Laboratory Problem which Utilizes Program GRAVITY

One experiment common to most first semester introductory physics courses is one in which the student is asked to determine the rate of acceleration associated with some component of the earth's gravitational force. At this point, it is useful to introduce the following convention: whenever the word "GRAVITY" appears thusly (fully capitalized), it refers to the particular computer program and its application being presented here.

GRAVITY's role enters with the student's independent determination of "the answer" to the problem assigned. In this case, it is the rate of acceleration of some rolling, sliding, or perpendicularly free-falling object. Then, in what may be considered a non-threatening encounter (GRAVITY

has no part in the student evaluation), the student presents the computer with both raw data and the calculated result. In return, the student is given a report on the quality of his work by comparing his results with those considered expert as well as those for the same experiment as performed by other students. A sample program run makes up figure 1. The program was written for the standard personal computer configuration thus all user-input is through a keyboard and the output to the student is through the machine's video screen. Optionally, output is available in printed form; figure 1 includes both screen output and "hard-copy" (output via a printer). The next section is a review of figure 1.

GRAVITY in the Laboratory

All of the typewritten material making up the first page of figure 1 would normally appear only on the video screen. The program output was planned for an 80 column by 24 line screen. This author has added hand-printing and hand-drawn bracing to distinguish actual computer output from notes added for discursive purposes here.

The material included in the section braced by the label "A" ought to be part of any stored program which is put into use infrequently. This section appears on the screen at the outset of the program run. As can be seen, it includes a reminder to the instructor about printer settings and presents whatever the 'master' program user has as options.

The section braced by the letter "B" is what may be called the apparatus or procedure data distinguisher. Rather than distinguishing the data by person or experimental team, it is grouped according to apparatus. It then becomes possible to ask reviewers to comment on whether or not "better" results tend can be associated with any one procedure in particular. Such a grouping also discourages attempts to personalize data quality. More will be said later about the value of identifying data this way.

Figure 1

```

[STOPPED: '1' will start program anew; '2' will add to
existing file. '999' at DEVICE input will dump to disc
(save file should/will be on current drive)
A-----'10' AT DEVICE INPUT WILL DUMP ALL TO PRINTER
-----SET BAUD RATE OF PRINTER AT 1200~ and characters to 10/in
OPTION? 2

Enter the number of the experiment for which you are providing data:
  dropped ball - (1)
  ball and rail - (2)
  air track - (3)
B<
Device or option selection? 3
This trial will be identified as NUMBER 68

Time in seconds? 1.72
Distance in meters? 1.125
Angle in degrees ? 5.2
Mass in kilograms ? .450
Has your data been entered correctly (1=yes; 0=no)? 1

  TRIAL  DEVICE  ANGLE  DISTANCE  MASS  TIME  DIFF
  68      3      5.2    1.125    0.450  1.72  14
OTHER TRIALS
  50      1      90     1.38     .084   .534   1
  51      3      2.4     .67     1.96   1.821  1
  52      3      2.4     .67     1.96   1.83  2
  53      3      2.4     .67     1.96   1.798  1
  54      2      11     1.3     .05    1.3  17
  55      2      11     1.3     .05    1.28  15
  56      2      11     1.3     .05    1.26  12
  57      2      11     1.3     .05    1.24   9
  58      2      11     1.3     .05    1.22   6
  59      3      4.2     .68     1.96   1.351  3
  60      3      4.2     .68     1.96   1.367  1
  61      3      4.2     .68     1.96   1.335  6
  62      3      4.2    1.1305   1.96   1.692  10
  63      3      4.2    1.135   1.96   1.682  11
  64      3      4.2    1.1305   1.96   1.682  11
  65      3      4.2    1.1305   1.96   1.688  10
  66      3      7.77   .645    .625   .89  22
  67      3      4.2    1.1305   1.96   1.679  11

PRESS <ENTER> OR <RETURN> TO INPUT MORE DATA

Enter the number of the experiment for which you are providing data:
  dropped ball - (1)
  ball and rail - (2)
  air track - (3)

Device or option selection? 10
IS PRINTER ON?
  TRIAL  DEVICE  ANGLE  DISTANCE  MASS  TIME  DIFF
  1       2      9.96    100    0.120  1.3  66672
  2       2      9.96     1.5    0.120  1.6  33
  3       2      9.96     2     0.120  2.0  41
  4       2      8.5     2     0.120  2.0  31
  5       1      90     1.709  0.045  0.6  1
  6       1      90     1.7    0.045  0.6  0
  7       2      8.22    1.8    0.120  1.4  27
  8       2      8.22    1.8    0.120  1.8  19
  9       2      8.22     2     0.120  2.0  29
  10      2      12     1.9    0.015  1.6  26

```

The number "68" in the line "This trial ...68" is set by the program with each new student input changing the value of this number by 1. The numbering is kept accurate by conditional statements; instructor-exercised options as well as altered entries do not increment the numbering procedure. In this program, the number "68" is highlighted by reverse video (dark characters, light background). This number is for the student's own reference.

Data (numbers only) provided by the student may be found in the series of boxes within the section braced by the letter "C". Unless the programmer is clever enough to employ "screen codes" for data entry (the procedures used by writers of "spread-sheet" programs), alteration of data which has been entered on some previous line requires a specific option such as the the last line of this section. If the student enters a "0" at this query, the computer runs through its prompts one more time without incrementing the trial number; previously-entered data is written over.

A dotted line encircles section "D". This array of information is the greatest number of lines displayed at any one time by a computer operating under the CP/M or MSDOS operating systems. In addition to the data set just entered, data from the most recent 18 trials is also displayed. Typing '999' at the device selection overwrites the student-data file which existed at the beginning of the session or it creates one if none existed previously. Figure 1 (section "E") is a sample computer outputs for one instructor option which may be exercised (other than quitting the program) after the students have entered data. When '10' is typed, all student data beginning with trial 1 is printed out.

Figure 2: The Program Listing for GRAVITY

The discussion which follows assumes an introductory knowledge of the BASIC language as it is implemented on virtually any computing system.

Statements 110-150: The use of "Arrays" is a standard approach to retaining several values of some variable within the execution of a program. "Dimensioning" sets the maximum number of these values to be stored. In this case, one-dimensional arrays have been created for each variable. The purpose of the DEFINT statement, which appears in line 180, conserves memory and speeds up disk read/write

Statement 170: Declares string variables (sets of characters which have no numerical value) to be used later with the PRINT USING statement (to be explained later)

Statements 230-350: Reminders to the Instructor-user: Practices which make for rapid reading are important to consider here; hence the use of PRINT statements to create blank lines along with tabbing. Bear in mind that this user needs to be reminded of any practices or "hidden" options whose inappropriate use may result in the "hanging-up" (the computer no longer recognizes input from the keyboard) or the "trashing" (the program is exited) of recently-entered student data. The pedagogical value of this particular operation is of particular interest to this author and will be discussed further in a later section.

Lines 410-490: This is the section where the terms under which the data may be sorted are described. The facts that keyboard entries are limited by the "sieve" statement in line 880, and that this running point marks the beginning of the student-use cycle make this the appropriate place to allow instructor intervention.

Statements 490-530: Keyboard entries of '10' and '999' will produce printouts of all data and the saving-to-disk of all student data. If a student user should inadvertently enter these numbers, no serious harm will come.

Statements 570-650: Each computer prompt is a request for one piece of data; I have had little success with prompts

Program Listing for GRAVITY

```

10 'Program name: GRAVITY
30 'Revised 7/8/87
50 'AUTHOR: Norman H. Fredette, Physics Department
70 '      Fitchburg State College, Fitchburg MA, 01420
90 KEY OFF
110 ' --- Dimensioning and declaration of variables
130 DEFINT C,Y,I,X,Z:C=1
150 DIM
G(300),DIFF(300),Y(300),M(300),AN(300),DI(300),T(300)
170 AS="###.##":BS="####":CS="##"
190 CLS
210 PRINT:PRINT:PRINT
230 ' --- Reminders to the instructor
250 PRINT"STOPPED; '1' will start program anew;'2' will add
to"
270 PRINT"existing file. '999' at DEVICE input will dump to
disc"
310 PRINT "--'10' AT DEVICE INPUT WILL DUMP ALL TO PRINTER"
330 PRINT"----SET BAUD RATE OF PRINTER AT 1200- and
characters to 10/in"
350 INPUT "OPTION";Z: IF Z=2 THEN GOTO 1230
370 CLS:PRINT:PRINT:PRINT
390 ' ---Student input of data
410 PRINT"Enter the number of the experiment for which you
are providing data:"
430 PRINT"  dropped ball - (1)"
450 PRINT"  ball and rail - (2)"
470 PRINT"    air track - (3)"
490 PRINT:PRINT:INPUT "Device or option selection";Y(C)
510 IF Y(C)=10 THEN GOTO 1430
530 IF Y(C)=999 THEN GOTO 1330

```

```

550 PRINT"This trial will be identified as NUMBER ";:COLOR
0,7:PRINT C:COLOR 7,0
570 PRINT: INPUT "Time in seconds";T(C)
590 INPUT "Distance in meters";DI(C)
610 IF Y(C)=1 THEN GOTO 650
630 INPUT "Angle in degrees ";AN(C)
650 INPUT "Mass in kilograms ";M(C)
670 ' ---opportunity to alter information
690 INPUT "Has your data been entered correctly (1=yes;
0=no)";Z
710 IF Z=0 THEN CLS:PRINT "Enter data anew:":GOTO 570
730 ' ---algebraic manipulation of student data
750 IF Y(C)=1 THEN AN(C)=90
770 G(C)=2*DI(C)/(SIN(AN(C)*3.1416/180)*T(C)^2)
790 DIFF(C) = ABS((G(C)-9.8)/9.8)*100
810 ' ---evaluation of data just entered
830 CLS
850 PRINT"  TRIAL    DEVICE    ANGLE    DISTANCE    MASS
TIME    DIFF"
870 PRINT TAB(5);C;
890 PRINT TAB(12);Y(C);
910 PRINT TAB(22);AN(C);
930 PRINT TAB(31);DI(C);
950 PRINT TAB(40);USING "###.##";M(C);
970 PRINT TAB(50);T(C);
990 PRINT TAB(58);USING BS; DIFF(C)
1010 ' ---listing of up to 18 most recent student trials
1030 IF C=1 THEN GOTO 1130 ELSE PRINT "OTHER TRIALS"
1050 FOR I=C-18 TO C-1:IF I>0 THEN PRINT
TAB(5);I;TAB(12);Y(I);TAB(22);AN(I);TAB(31);DI(I);TAB(40);M(I);
1070 IF I>0 THEN PRINT TAB(50);T(I);TAB(58);
1090 IF I>0 THEN PRINT INT(DIFF(I))
1110 NEXT:GOTO 1130
1130 PRINT "PRESS <ENTER> OR <RETURN> TO INPUT MORE DATA"

```


Figure 2 (cont.)

```

1150 AAS=INKEY$:IF AAS=CHR$(13) GOTO 1210
1170 GOTO 1150
1190 ' --- save all data to disc; overwrite existing file
1210 C=C+1:GOTO 370
1230 OPEN"I",1,"ROLL6.SAV"
1250 INPUT#1,C:FOR I=1 TO C:INPUT#1,
Y(I),DI(I),AN(I),M(I),T(I),G(I),DIFF(I):NEXT
1270 CLOSE #1
1290 C=C+1:GOTO 370
1310 ' --- retrieve data from previous lab(s)
1330 OPEN"O",1,"ROLL6.SAV":C=C-1
1350 WRITE#1,C:FOR I=1 TO
C:WRITE#1,Y(I),DI(I),AN(I),M(I),T(I),G(I),DIFF(I):NEXT
1370 CLOSE #1:C=C+1
1390 GOTO 410
1410 ' --- hard copy of all student data in memory
1430 PRINT"IS PRINTER ON?"
1450 LPRINT"  TRIAL  DEVICE  ANGLE  DISTANCE  MASS
TIME  DIFF"
1470 FOR I=1 TO C-1:LPRINT
TAB(5);I;TAB(12);Y(I);TAB(22);AN(I);TAB(31);DI(I);
1490 LPRINT TAB(40);USING "###.###";M(I);
1510 LPRINT TAB(50);USING AS;T(I);
1530 LPRINT TAB(56);USING BS;DIFF(I):NEXT:GOTO 410
1550 END

```

which request several pieces of data separated by commas. Separate prompts for each variable also allow for easier transformation to another collection of variables. Most programmers tend to limit user input to all computer prompts with statements which act like a sieve; permitting the program to continue only if keyboard entries fall within certain bounds. Because these statements are often difficult to write (the programmer must anticipate all inappropriate entries), this author often doesn't bother with them at all because the risk has never proven that much of a problem.

Statements 690-710: This is an important option because students often confound their data entries; a fact which becomes obvious to them only when the entry process is complete. If the student enters '0', the trial number is not incremented and the entire query sequence is run through once again.

Statements 750-790: Here, the computer calculates the student result and compares it with the "accepted" value. Note that the student is not informed of this calculated result in the screen-print which comes next.

Statements 850-990: Along with a repeat of the data just entered, the student is given a comparison of other student result as well as some indication of how each result compares to theoretical expectations from the simplest system. PRINT USING statements are designed to accomplish two things: 1.) to limit the reported digits;; 2.) to "right-justify" the numbers for easier (more rapid) comparison. PRINT USING statements cannot be mixed on the same program line in this particular version of BASIC.

Line 1030: a sieve statement for the case of no previous student data

Statements 1030-1170: Produces a listing of other student trials. The number reported is limited to a screenful of both the student's own data and the most-recently entered data for the same device (or procedure).

Statements 1190-1370: This sequence produces the data transfer between computer and disc storage. The statements here describe "sequential file" operations. An alternative operation, called "random file" accessing is preferred by some programmers because this latter type can be designed to take up less disc space but it must also be defined more carefully.

Statements 1410-1530: This is the sequence which provides a carry-away copy of all student data and calculated results; note that the calculation(s) required of the student are included here.

Using Computers to check student calculations

Programs such as the one to be discussed were developed as a way of encouraging students to follow their data through to a calculated result while the apparatus is still available to verify the raw measurements. Some may find it "overkill" to use a computer as a calculation check; others see this device as providing an opportunity for the laboratory instructor to concentrate his or her efforts on helping the student comprehend the physics rather than identifying the mathematical reason for an inappropriate calculated result.

Clearly one of the goals of any physics course is the achievement, on the part of the student, of a certain degree of "physics literacy". The make-up of that literacy is often moot so the intent of providing this computer interaction is not so much an argument for the content as it is the style.

Another goal addressed through this program is that of ensuring that the student has information applicable to writing an appropriate lab report before he or she leaves the data-gathering time and place.

Evaluating Data from the Ballistic Pendulum Experiment

The Ballistic pendulum remains an experiment in many introductory physics laboratories because it provides an accurate case of the dynamical issues associated with "perfect" inelastic collisions (i.e. - momentum is conserved while mechanical kinetic energy is not). The experiment requires only two operations. First, the student "fires" the ball from a position which is located about one meter up from the floor; the pendulum has been removed and the gun is horizontal. Using information about the ball's horizontal and vertical displacements, the student presumably can determine the ball's initial velocity as it leaves the gun. In reality, few students can actually do this successfully on the first try. Furthermore, without prodding, few realize that their incorrect answer is indeed incorrect. It then becomes someone's responsibility to help them realize the situation and to do so in a developmentally-helpful way.

The second operation is that of firing the ball into the pendulum. Using measurements of the system's change in vertical displacement after the collision (along with the masses and just-determined initial velocity of the ball), changes in momentum and mechanical energy of each member of the system are determined and physically evaluated.

Using BALLPEND in the Laboratory:

This author has used a single-page laboratory instruction sheet for this experiment in which the operations are described but the calculations are not. Students are simply asked to determine several descriptors from some measurement or measurements.

Calculated values requested are:

1. Initial velocity of the ball from the displacement components;
2. Kinetic Energy of the ball before impact with the pendulum
3. Change in Potential Energy of the ball/pendulum after impact
4. Initial kinetic energy of the ball/pendulum just after impact from Changes in momentum.

Discussion of the Sample Run:

Figures 3a and 3b represent example uses of this program as might be experienced by students. The section labeled "A" in figure 3a shows the interaction with a person who has done all of the calculations correctly. Values for all directly-observed data are requested in the units as measured (before any conversion); the rationale here being that many calculated values turn out to be incorrect simply because of mistakes in unit-conversion. It is not unusual for a person, when converting grams to kilograms, to divide by 100 instead of the required 1000 and the program has been structured to pick up such errors.

Notice that the phrase "..value.." corresponds to your data" is used rather than some other phrase which passes judgement on the quality of the data. For those who successfully complete the calculations correctly, the bottom line asks the question — "... is this acceptable according to theory?". The direct implication is: this 81% difference is a function of something other than miscalculation. It is likely related to either a failure to be careful enough or, it is a physically expected difference! Sorting out the options is left to the written report.

Section "A" of figure 3b shows what happens when the user enters a miscalculated value (in this case, the person correctly calculated the velocity but incorrectly calculated

Figure 3a
Completely Successful Sample Run for Ballistic Pendulum

```

EVALUATIONS OF CALCULATIONS RELATING TO THE BALLISTIC PENDULUM
If basic data (mass of the ball etc) has already been entered,
and, you DO NOT wish to change them, then ---
Enter the number of the trial; otherwise, enter "0"? 0
This trial will be identified as NUMBER 1
Mass of the ball (grams).....? 63
Mass of the pendulum (grams).....? 2.87
The following two requests relate to the situation in which the
pendulum is NOT in place:
Horizontal distance traveled by ball (meters).....? 2.85
Vertical distance traveled by ball (meters).....? .89
Your calculation of the ball's initial velocity (m/s).....? 6.69
Has your data been entered correctly (i/yes; 0/no)? 1
Your value for the velocity corresponds to your data --Good going!
Kinetic Energy of the ball before collision (J).....? 1.41
Calculation of this KE OK: --Good

Change in vertical displacement of ball/pendulum (cm).....? 7.1

Change in Pot. Energy of the ball/pendulum after collision (J).....? .243
Our calculations for the potential energy agree. Good

Now, based on Conservation of momentum for the ball/pendulum
system, what must be the Kinetic Energy of the ball/pendulum
immediately following the collision on (J) .....? .254
Your calculation of the ball/pendulum's kinetic energy is
correct according to your data. GOOD!

YOUR TECHNIQUE MUST HAVE BEEN GOOD TOO BECAUSE YOUR ERROR WAS LESS THAN 1%
CONGRATULATIONS ----- BUT ...

The difference between the Kinetic Energy of the ball before the
collision and the ball/pendulum combination as it begins its upward journey
is 1.15% Joules; this represents a difference of 81 %
--- is this acceptable according to theory?
Press <ENTER> or <RETURN> to continue

```

Figure 3b
Additional Sample Runs of Ballistic Pendulum

```

EVALUATIONS OF CALCULATIONS RELATING TO THE BALLISTIC PENDULUM
If basic data (mass of the ball etc) has already been entered,
and, you DO NOT wish to change them, then ---
Enter the number of the trial; otherwise, enter "0"? 1
This trial will be identified as NUMBER 1
Mass of the ball (grams).....? 63
Mass of the pendulum (grams).....? 2.87
The following two requests relate to the situation in which the
pendulum is NOT in place:
Horizontal distance traveled by ball (meters).....? 2.85
Vertical distance traveled by ball (meters).....? .89
Your calculation of the ball's initial velocity (m/s).....? 6.69
Has your data been entered correctly (i/yes; 0/no)? 1
Your value for the velocity corresponds to your data --Good going!
Kinetic Energy of the ball before collision (J).....? .89
Using the data provided here, your calculation of this last
quantity is not within 2% of the value calculated by the computer.
Please check your work.
Press <ENTER> or <RETURN> to continue

EVALUATIONS OF CALCULATIONS RELATING TO THE BALLISTIC PENDULUM
If basic data (mass of the ball etc) has already been entered,
and, you DO NOT wish to change them, then ---
Enter the number of the trial; otherwise, enter "0"? 1
Mass of the ball (grams).....? 63
Mass of the pendulum (grams).....? 2.87
The following two requests relate to the situation in which the
pendulum is NOT in place:
Horizontal distance traveled by ball (meters).....? 2.85
Vertical distance traveled by ball (meters).....? .89
Your calculation of the ball's initial velocity (m/s).....? 6.69
Has your data been entered correctly (i/yes; 0/no)? 1
Your value for the velocity corresponds to your data --Good going!
Kinetic Energy of the ball before collision (J).....? 1.41
Calculation of this KE OK: --Good

Change in vertical displacement of ball/pendulum (cm).....? 7.1

Change in Pot. Energy of the ball/pendulum after collision (J).....? .082
Using the data provided here, your calculation of this last
quantity is not within 2% of the value calculated by the computer.
Please check your work.
Press <ENTER> or <RETURN> to continue

```

the kinetic energy. The 2% allowance is provided for "rounding-off" and is based largely on experience with this particular experiment. The program is written to interrupt at the earliest point at which a miscalculated value is entered and then print the message shown at the bottom of this section. Recall that students are asked to note their particular trial number so that when they do return to the computer, they need not re-enter all previously identified-as-correct raw data and calculated values.

Section "B" of figure 3b is an example of a case where the student had previously entered an appropriate value for velocity but not for energy. Thus when that person enters "2" (the trial number) the terminal prints out all the previous information (stored in computer memory) up to the last incorrect value; it pauses for the newly calculated value and if found acceptable, goes on to the next request.

Program Listing for BALLPEND: Figure 4

There were three main issues which had to be resolved in the writing of this program and all three were related to the use of logical arguments. First, there were those which would evaluate student input; these are straight-forward and not unlike those appearing in GRAVITY. The second use of logical arguments related to the identification of all data and calculated values for some given trial. The third involved the printing out of stored information as the student returns to enter information anew; these last arguments turned out to be the most difficult to write.

Space does not allow for a detailed discussion of the program so suffice it to say that, except for the more complicated logical structure, programming style parallels that discussed in the case of GRAVITY.

Figure 4

Listing for Ballistic Pendulum Program

```

10 ' Program name: BALLPEND.BAS ; REVISED 7/9/87
30 ' Author: Norman H. Fredette, Physics Department
50 '           Fitchburg State College, Fitchburg, MA; 01420
70 ' --- Dimensioning of variables
90 DEFINT C,I,Z:C=1
110 DIM
MB(300),MP(300),X(300),Y(300),VB(300),H(300),KE(300),L(300)
130 DIM
VC(300),KEC(300),PA(300),KA(300),KAC(300),PAC(300),DIFF(300)
150 CLS:PRINT:PRINT:PRINT
170 ' --- Student input of data
190 PRINT"EVALUATIONS OF CALCULATIONS RELATING TO THE
BALLISTIC PENDULUM"
210 PRINT
230 PRINT "If basic data (mass of the ball etc) has already
been entered,"
250 PRINT "and, you DO NOT wish to change them, then ---"
270 INPUT "enter the number of the trial; otherwise, enter
~0~";J
290 IF J>0 THEN PRINT "Basic data for trial
#";J:G=C:C=J:GOTO 1790
310 PRINT "This trial will be identified as NUMBER";:COLOR
0,7:PRINT C:COLOR 7,0:L(C)=0
330 INPUT "Mass of the ball
(grams).....";MB(C)
350 IF MB(C)=999 THEN 1730
370 INPUT "Mass of the pendulum
(grams).....";MP(C)
390 MP(C)=MP(C)/1000:MB(C)=MB(C)/1000
410 PRINT "The following two requests relate to the
situation in which the"
430 PRINT "pendulum is NOT in place:"

```

Figure 4 (cont.)

```

450 INPUT "Horizontal distance traveled by ball
(meters).....";X(C)
470 INPUT "Vertical distance traveled by ball
(meters).....";Y(C)
490 INPUT "Your calculation of the ball's initial velocity
(m/s).....";VB(C)
510 INPUT "Has your data been entered correctly (1=yes;
0=no)";Z
530 IF Z=0 THEN CLS:PRINT "Enter data anew:";GOTO 330
550 ' --- next GOTO is the math eval. of vel. of ball before
collision
570 GOTO 970
590 COLOR 0,7:PRINT "Your value for the velocity corresponds
to your data -Good going!";COLOR 7,0:PRINT:L(C)=1
610 INPUT "Kinetic Energy of the ball before collision
(J).....";KE(C)
630 ' --- next GOTO is math eval. of KE of ball before
collision
650 GOTO 1130
670 COLOR 0,7:PRINT "Calculation of this KE OK; --
Good";COLOR 7,0:PRINT:L(C)=2
690 INPUT "Change in vertical displacement of ball/pendulum
(cm).....";H(C)
710 H(C)=H(C)/100
730 PRINT:INPUT "Change in Pot. Energy of the ball/pendulum
after collision (J)..";PA(C)
750 ' --- next GOTO is math eval of change in PE after
collision
770 GOTO 1190
790 COLOR 0,7:PRINT "Our calculations for the potential
energy agree. Good";:COLOR 7,0:
810 PRINT:L(C)=3

```

Figure 4 (cont)

```

830 PRINT:PRINT "Now, based on Conservation of momentum for
the ball/pendulum "
850 PRINT "system, what must be the Kinetic Energy of the"
870 INPUT "ball/pendulum immediately following the collision
(J) .....";KA(C)
890 ' --- next GOTO is math eval of KE of ball/pendulum just
after collision
910 GOTO 1250
930 CLS
950 ' --- all math evaluations follow
970 VC(C)=X(C)*SQR(9.8/(2*Y(C)))
990 IF ABS(VC(C)-VB(C))<.02*VC(C) THEN 590
1010 PRINT "Using the data provided here, your calculation
of this last"
1030 PRINT "quantity is not within 2% of the value
calculated by the computer."
1050 PRINT "---Please recheck your work."
1070 GOTO 1570
1090 IF G>0 THEN C=G:G=0: C=C+1:GOTO 150
1110 C=C+1:GOTO 150
1130 KEC(C)=.5*MB(C)*((VB(C))^2)
1150 IF ABS(KEC(C)-KE(C))<.02*KEC(C) THEN 670
1170 GOTO 1010
1190 PAC(C)=(MB(C)+MP(C))*H(C)*9.8
1210 IF ABS(PAC(C)-PA(C))<.02*PAC(C) THEN 790
1230 GOTO 1010
1250 KAC(C)=.5*(MB(C)*VB(C))^2/(MP(C)+MB(C))
1270 IF ABS(KAC(C)-KA(C))<.02*KAC(C) THEN 1310
1290 GOTO 1010
1310 COLOR 0,7:PRINT "Your calculation of the
ball/pendulum's kinetic energy is"
1330 PRINT "      correct according to your data.
GOOD!";:COLOR 7,0:
1350 PRINT:L(C)=4

```



```

1370 DIFF (C)=ABS(KA(C)-PA(C)):PRINT:PRINT:PRINT
1410 IF DIFF(C)<.03 THEN COLOR 0,7:PRINT "YOUR TECHNIQUE
MUST HAVE BEEN GOOD TOO BECAUSE YOUR ERROR WAS LESS THAN
3%"
1430 IF DIFF(C)<.03 THEN PRINT "      CONGRATULATIONS ----
---";:COLOR 7,0:
1450 IF DIFF(C)<.03 THEN PRINT "  BUT ...":GOTO 2190
1470 IF DIFF(C)<.08 THEN PRINT "YOUR EXPERIMENTAL ERROR IS A
BIT HIGH FOR THIS"
1490 IF DIFF(C)<.08 THEN PRINT "PARTICULAR SET-UP; TRY TO DO
IT A LITTLE MORE CAREFULLY
1510 IF DIFF(C)<.08 GOTO 1570
1530 PRINT "YOUR EXPERIMENTAL ERROR (GREATER THAN 8%)
SUGGESTS THAT YOUR MEASURING TECHNIQUE WAS A BIT SLOPPY."
1550 PRINT "DO IT AGAIN USING MORE CARE."
1570 PRINT "Press <ENTER> or <RETURN> to continue"
1590 X$=INKEY$:IF X$=CHR$(13) GOTO 1090
1610 GOTO 1590
1630 PRINT "PRESS <ENTER> OR <RETURN> TO CONTINUE"
1650 X$=INKEY$:IF X$=CHR$(13) GOTO 1370
1670 GOTO 1650
1690 ' --- section which follows allows for entry of
calculated values only
1710 ' --- assumption is that basic measurements are OK
1730 INPUT "TRIAL NUMBER";J
1750 PRINT "This trial will be identified as NUMBER";:COLOR
0,7:PRINT J;COLOR 7,0
1770 PRINT
1790 PRINT "Mass of the ball
(kilograms).....";MB(C)
1810 PRINT "Mass of the pendulum
(kilograms).....";MP(C)
1830 PRINT "Horizontal distance traveled by ball
(meters).....";X(C)

```

```

1850 PRINT "Vertical distance traveled by ball
(meters).....";Y(C)
1870 IF L(C)<1 THEN GOTO 490
1890 PRINT "Your calculation of the ball's initial velocity
(m/s).....";VB(C)
1910 IF L(C)<2 THEN GOTO 610
1930 PRINT "Kinetic Energy of the ball before
collision.....";KE(C)
1950 IF L(C)<3 THEN GOTO 690
1970 PRINT "Height to which ball/pendulum was pushed
(m).....";H(C)
1990 IF L(C)<4 THEN GOTO 730
2010 PRINT "Potential Energy of the ball/pendulum at end of
trip (J).....";PA(C)
2030 IF L(C)<4 THEN GOTO 830
2050 PRINT "Kinetic energy of the ball/pendulum after
collision (J).....";KA(C)
2070 IF L(C)<5 THEN GOTO 690
2090 IF MB(C)<>999 THEN GOTO 1570
2110 PRINT "Final kinetic energy
(computer).....";KAC(C)
2130 PRINT "Final potential energy
(computer).....";PAC(C)
2150 PRINT "Difference -- computer/user input
.....";DIFF(C)
2170 GOTO 1570
2190 PRINT:PRINT "The difference between the Kinetic Energy
of the ball before the"
2210 PRINT "collision and the ball/pendulum combination as
it begins it upward journey is:"
2230 PRINT ABS(KA(C)-KE(C));"Joules; this represents a
difference of ";INT(ABS((KA(C)-KE(C))/(KE(C))*100));"%"
2250 PRINT " --- is this acceptable according to theory?"
2270 GOTO 1570

```

Conclusion and Summary

Two prototype programs which may be altered by editing with a word-processor were presented. The main purpose of the first (GRAVITY) was to give students an evaluation of the quality of their own data as well a summary of how well other people have done with the same procedure or piece of apparatus. The instructor is also given the opportunity to see how the results were for a particular lab-group (the most recent trials), or for a particular procedure or set-up.

The second, BALLPEND, was presented as an example of an application where student calculations are evaluated before they leave the laboratory. The pedagogical aspects of these applications will now be discussed.

Evaluating Quality of Data

There is growing acceptance of the view that education is a matter of enhancing the learner's restructuring of his or her own conceptions of the physical world. Many educators believe that the restructuring process is a highly personalized one. This author contends that the computer programs presented here assist the students in evaluating their own data and thus are an important aspect of any educational experience.

Typically, laboratory students want to know "how they are doing"; they want to be assured that their data is of some significance. If the laboratory procedure is not set up to encourage "data-checking", many students will blindly accept whatever results were obtained and then go on to either alibi the inappropriate results or alter them so that they fall within some acceptable range. Most laboratory course structures, at least in introductory physics, do not allow students to redo their work after they have reviewed it outside of the laboratory; the laboratory is mostly viewed as an opportunity to have a "hands-on" encounter with the topics considered in the lecture-portion of the course

which in most instances are collections of loosely-related topics. Thus the lecture schedule sets the pace of the laboratory experience and the student is not permitted to either redo or discuss meaningless experimental results acquired in previous sessions.

Use of a computer programs such as those presented here permit, and indeed encourage, data-evaluation which:

- 1.) takes place in the same session as that in which the work was done;
- 2.) includes meaningful information for evaluation of data-quality yet requires that the student manipulate their own values to determine the result required by the instructor;
- 3.) is not particularly ego-threatening to the student (the instructor will not be informed about any individual's "poor" results);
- 4.) is "officially" sanctioned (not clandestine).

Benefits to the Instructor

Along with the benefits to the student, the instructor is able to evaluate the effectiveness of any particular laboratory procedure or set of procedures. A review of student data for some interval (individual lab, day or whatever) can yield clues about whether or not the students were prepared for that particular investigation. One can also pick up on pieces of apparatus that are not working properly and effect a repair before the next group of students comes in to work.

Benefits to the Researcher

The program easily can be altered to allow the retention of separate student data sets as well as the accumulated data file (add another disc-write statement). A researcher can then compare the results of having varied any aspect of the course structure like lecture style or laboratory procedure.

REFERENCES

- Clement, John, "Students' Preconceptions in Introductory Mechanics", American Journal of Physics, 50(1), pp. 66-71
- Fredette, N.H. and Clement, J.J. "Student Misconceptions of an Electric Circuit: What do they mean?", Journal of College Science Teaching, 10(5), pp. 280-285, 1981
- Fredette, N.H., and Lochhead, J.J. "Student Conceptions of Simple Circuits", The Physics Teacher, 18(3), pp 194-198, 1980
- Fredette, N.H., "College Student Conceptions of Electric Circuits", unpublished EdD dissertation, University of Massachusetts, 1981
- Riley, M. "Instructional Methods that Make a Difference: Structural Understanding and the Acquisition of Problem-Solving Skill", expansion of a paper presented at the meeting of the AERA, April, 1983
- Steinberg, Melvin "Electric Potential from Hands-On Experiments", Paper presented at NESAAAPT, Wellesley, Mass. April, 1984.

Erroneous Conceptions of Computing Concepts

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With the increasing influence of computers on society, educators recognize the need for, and the importance of, preparing today's youth for a highly computerized future. This has created an accompanying need for educating preservice and inservice teachers. There has been much debate over the content of such computer training (Bowman, 1986; King, 1985), but little seems to be gained by rehashing that debate. In Texas, the content is dictated by the definition of the required middle/junior high school computer literacy course: (a) use of utility programs (e.g., word processing), (b) writing simple programs, and (c) knowledge of terminology, career options, computer history, ethics, etc.

One concern about requiring computer literacy courses for teachers is whether those teachers acquire accurate understandings of fundamental computing concepts. There has been much research on concepts both in general and in specific disciplines such as mathematics (Harrison & Harrison, 1986; Quintero, 1986) and science (Osborne & Wittrock, 1983; Posner & Gertzog, 1982), but there has been virtually no study of the attainment of specific or fundamental computing concepts in any computing context other than programming (e.g., duBoulay, 1986; Pea, 1986; Sleeman, Putnam, Baxter, & Kuspa, 1986). The

knowledge base derived from programming research is insufficient to permit understanding of the more general and diversified content of computer literacy courses.

Because computer technology and software change rapidly, specific skills are likely to become quickly obsolete. Too, commands and functions vary between software packages and between hardware (e.g., keyboard configuration, presence or absence of a "mouse"), and even the interactions of hardware and software vary. Accurate understanding of computers and computing, that is, well developed concepts, is the key to staying computer literate in these differing situations. Transfer of what is learned to new situations depends on the underlying conceptual base. Hence it is important to know the nature of this conceptual base and how it develops among computer literacy students.

Which computing concepts warrant immediate study is debatable, but some seem very fundamental to computing in general and are common across a large variety of computing applications. How computing concepts are to be defined or explained and what may be accepted as sufficient evidence of concept attainment is also at issue. There are many definitions of common computing concepts, with differing levels of formality and complexity. For example, one definition of input/output is "[referring] to having input and output capabilities" (Hawaii, 1985, p. 121). Such a definition hardly begins to unveil the complexity of the input/output concept. If a student gave this definition either during an interview or on

an exam, further inquiry would be needed to verify whether s/he actually understood the concept.

Command is defined as a "request to the computer that is executed as soon as it is received" (Hawaii, 1985, p. 126). This is an attempt to differentiate command from instructions included in a procedure; these are usually referred to as statements. A statement is defined as a "single meaningful expression or instruction in a high-level language," which does not seem restrictive enough. For example, this does not differentiate adequately between command and statement and does not account for the role of a statement either as a systems command, a command entered for immediate execution, or a statement in a program. Knowing whether computer literacy students acquire understanding of such distinctions is an important step in knowing the conceptual base teachers take back to their classrooms. Data on such knowledge is best obtained through one-on-one interviews with computer literacy students.

In an inquiry study, one expects responses which relate to the previous experiences. For example, a seventh grader's answer to "What is a computer?" might reflect dimensions of a microcomputer or a video game, but a bank president's answer might reflect dimensions and applications of a mainframe. People bring prior knowledge and experiences to any learning situation; that knowledge affects the development of concepts. Learning could benefit from teaching which adapts to this prior knowledge and makes use of preexisting ideas in the concept

building process (Osborne & Wittrock, 1983). It is important, therefore, to identify those preexisting ideas and experiences.

There are many areas of needed research in computer education: mode of computer use, interaction of computer involvement with student characteristics, design of instructional materials (Waugh & Currier, 1986), Logo (or BASIC) and development of problem solving skills, database access and acquisition of research skills, and word processing and writing. However, until we know what concepts students actually acquire, these interests cannot be adequately addressed.

Study One

This informal study was an initial attempt to determine what concepts preservice teachers had as they exited a computer literacy course. The course, required of all juniors and seniors at the University of Calgary, had five parts: Logo, word processing using Bank Street Writer (BSW), evaluation of instructional software, database software, and BASIC. Apple II computers were used throughout.

Subjects

The subjects were 25 students enrolled in one section of the course in spring 1985. All students were under 25 years old.

Method

Data were gathered through questions on mid-term (Logo and word processing) and final (cumulative, but emphasizing the last three sections) examinations. Errors were coded through analysis of written responses.

Results

One final exam question exhibited the most obvious misconceptions. These data are presented in Figure 1. (See attached.)

Of the 25 students, 13 thought that programs could be executed in BSW and 17 thought that a Logo command (other than the procedure name) would execute the program (procedure) in RAM. Further, 13 thought that POTS would list a procedure's commands (as opposed to procedure titles) on the screen. These responses indicate potential misunderstanding about the fundamental nature and function of commands. Other important misunderstandings are seen in the confusion between clearing RAM and clearing the screen in BSW and in the failure to identify a command for erasing a file in all three settings. This may indicate confusion about the nature of a file.

Perhaps students do not understand how the parts of a computer work together or interrelate. That is, they don't understand the difference between activating one particular part (e.g., clear the screen only) without also activating a corresponding part (e.g., clear RAM simultaneously).

An alternate conclusion is that students do not know where information resides within a computer system at any given time. For example, the image on the monitor is a "reflection" of the information stored in memory, but changing information in one location does not automatically cause the information in the other location to be changed.

A mid-term exam question revealed misconceptions about

programming constructs. These data are presented in Figure 2. (See attached.)

The proportionality errors may be related more to the notion of intent of the procedures rather than to misinterpretation of particular commands. That is, when most people draw pictures of flags on poles, they behave as if the flagpole should be proportional to the size of the flag being flown. Indeed, in real life this is usually the case. When students interpreted the intent of the procedures as drawing flags on poles it may have been impossible for them to divorce this intent from the operation of the procedures. Pea, Soloway, and Spohrer (1987) have characterized this as an intentionality bug and view it as a special instance of a more general class of bugs arising out of overgeneralization of the conversation metaphor to programming. Unlike people, the computer does not behave as an informed listener; rather, all details must be made explicit. Failure of the subjects to understand the explicitness required may point to misconceptions about programs.

The misinterpretation of the values of the variables may relate to misunderstandings of the notions of data. That is, failure to identify the difference between the constant and the variable in the FLAG procedure and the attempts to keep physical limitations constant in the drawings may be symptoms of misunderstanding about what information is passed to the computer by the procedure call.

Study Two

This was a follow-up study designed of conceptual

understanding. The primary objective was to identify the path of development of fundamental computer concepts across instruction in the course. The computer literacy course was designed for freshmen and sophomores prior to enrolling in the teacher preparation program at the University of Houston; it had five parts: Logo, word processing, database software, spreadsheet software, and BASIC. Apple II computers were used throughout.

Sample

Subjects were six volunteer interviewees taken from one section of the course in summer 1986. This section was taught in 21, two-hour sessions over a five-week period; open lab time was provided each day and on Saturdays. Each of the programming sections took about five sessions, and each of the utility program sections took about three sessions. Two other students were lost as subjects because they dropped the course. All six subjects were female; ages ranged from 22 to 40, with a median of 31. Previous computer experience included none (two subjects), some data entry experience (three subjects), and a computer science degree completed 13 years earlier (one subject). These subjects, then, may represent older, and on the average somewhat more experienced, persons than are typically found in an undergraduate computer literacy course.

Content Focus of the Study

Five concepts were selected for study: command, data, file, memory, and program. These were selected because of their

fundamental importance to computing.

Procedures

Interviews were scheduled during the first, third, and fifth weeks of the course; at these times students were, respectively, (a) beginning Logo, (b) working with the database, and (c) finishing BASIC. Interviews were not part of the instruction of the course and the subjects were told that nothing they said would be discussed with their instructor. Interviews were open-ended; questions on each of the five concepts were written for the opening interview. The second and third interviews included some of these questions and modifications of others of these questions. Interviews were audio taped and transcripts were prepared from these tapes; these transcripts were the data for the analysis.

Results

Each of the five concepts is dealt with separately. The concepts of file, memory, and program are dealt with quite explicitly in the course, in each application setting and in each programming language. For example, the contents of files created and the procedures for creating and deleting files are carefully discussed. Command and data are not discussed as carefully. Consequently, contrasting these two types of concepts illustrates ways students both react to instruction and develop or retain concepts on their own.

Concept: Data. S1 (that is, subject 1) had no previous computer experience. During I1 (that is, interview 1) she admitted to not being able to give an example of data, but she

guessed that it is "what you get out after you put something in." Data is put in manually and is kept in the temporary memory and permanently in the disk drive. During I2 she said, "Don't know." in response to "What is computer data?" During I3 she described data as information or a collection of information. As an example, she gave FORWARD 10 (from Logo). When asked if that fit her definition of command (i.e., specific instructions for the computer to do a certain task), she stated, "that's not a command, that's data." A second example of data was values (e.g., 75.6) in a spreadsheet. She further explained that in Logo, things typed in are data, and system controls like SAVE are commands. Later she repeated this notion; "anything you type in [in BASIC] is data."

S2 had used a microcomputer on only one previous occasion. During I1 she said that data was information "about" computers. It is typed into the computer and kept on a disk. She could not give any examples of data. During I2 she explained data as information stored on disk. She said that in Logo, data is something like a program. In a database, data is the records you work with, specifically "the name like John Jones or whatever." During I3 she explained data as "something important" you have stored.

S3, S4, and S5 each had some experience as computer users. During I1 they typically defined data as something typed in and stored in memory. During I2 commands from Logo (e.g., FORWARD 10) were typically given as examples of data. During I3, data was described as information to be stored or used.

S6 had completed a computer science degree some 13 years earlier but admitted having forgotten much of the information she had learned. During I1 she described data as information (e.g., names, dates) that comes into the computer from an external source (e.g., keyboard, modem) and is stored in temporary memory until stored on disk. During I2 her examples of data included "lists of [procedure] titles" in Logo and fields in a database; but in the word processor "not much is data, unless the letter itself is the data." During I3 she described data as "extra information to work with."

In summary, the biggest confusion seemed to be that data is what people type into a computer. At one level this is correct, but it is far too restrictive. None of the interviewees, for example, talked in terms of using data for debugging their programs or as values passed to procedures in Logo. Yet all of them used data in these ways. During I2 the tendency to identify commands as data seemed to peak. More attention seems needed to help students distinguish data from information.

Concept: Files. During I1, S1 guessed that a file was a back-up copy of a disk, which contains "any information you want." During I2 she guessed that a file was the same as a program. During I3 her examples of files were PICTURE (containing the procedures for drawing the picture required in the assignment) in Logo and a set of two or more records in a database.

S2 described a file during I1 as a bunch of organized

information which is typed in and kept on a disk. During I2 she described the contents of a file as information, for example, a program in Logo. During I3 her examples were (a) different programs in Logo, (b) "the program you've named" in the word processor, and (c) a group of related information in the database.

During I1, S3 claimed complete ignorance on the subject. During I2 she described a file as something saved on on the disk, with data as the contents. During I3 she gave accurate examples of files for all applications except database, for which a file was "a field."

S4 described a file during I1 as "where you store your information on the diskette. A file is created by initializing a diskette." During I2 she described a file as a location in computer memory containing "inputs or outputs or variables." The location is in the "RAM or ROM, either." During I3 her examples seemed to focus on bits of information; e.g., columns of numbers in a spreadsheet.

During I1, S5 said a file was "catalog files, lists of data" containing mailing lists, customer purchases, etc. During I2 she said that a file stores data on a disk. During I3 all of her examples of files were accurate.

S6 said during I1 that a file was a place to store a list of information. A file can exist without a disk as long as the power is on. During I2 she described a file as a "list of stuff like commands." In Logo a file contains commands in a procedure. Her examples were accurate during I3.

In summary, the notion of file seems confused by vagueness about location of a file (e.g., RAM or ROM or disk) and what goes into a file (e.g., commands, inputs, variables, program). There is interference with the notions of a procedure and program and there is confusion (perhaps like the set/subset confusion in mathematics) between a file and particular types of information stored in the file (e.g., field, variables, commands).

Concept: Memory. Early in I1, S1 defined memory as "the disk drive" and upon explicit questioning reaffirmed her position that the disk drive and the memory were the same. Further, she stated that the "output from the disk drive is permanent" and that the "temporary memory is the central processing unit." When asked how long the computer remembers what you type, she said "forever." During I2 she said that the permanent memory "is in the CPU called ROM" and that temporary memory is RAM, but she seemed to have lost the relationship of the disk (or disk drive) to the concept of memory. By the time of I3 she seemed to have accurate concepts of what was temporary and what was permanent, but she insisted that the only way to change temporary memory was "by editing."

During I1, S2 stated that the internal memory is only ROM, and the external memory is on the disk. She did not know whether the disk and the memory were the same, and she did not know whether memory changed when a user typed something. She seemed to believe that typed information went directly to the disk. During I2 she said that "ROM resides

within the computer. RAM is just temporary. Don't know where RAM is." She did know that typing caused memory to change, but she could not explain how long a computer remembered something. During I3 she could not explain what was put in memory when each application program was started ("I only know what I see.") but she did accurately explain how to change memory in each case.

S3 showed a reasonably accurate notion of memory in I1, although she identified memory as "in the disk" and wanted to equate these two notions "because they tell me to put that thing [disk] in before you can run the computer." She distinguished between RAM and ROM, and she said that "without saving, [the computer] remembers only then; remembers only what is shown on screen." During I2 she was more confident that the disk and memory were identical, but she had given up the notion that only what is on the screen is remembered. In response to a question about what is in memory when an application is begun, she said that the turtle and "maybe a procedure" were in memory in Logo, that the menus were in memory for the utility programs, and that "whatever may have been saved before" was in memory for BASIC. She did seem to have accurate procedures for changing temporary memory for all five environments.

S4 displayed only minor inaccuracies in her understanding. During I1 she said that "you must keep typing or information will be lost; even stepping away for a while results in information loss on the IBM." She had apparently not learned

about refreshing the screen. During I3 she said that to change temporary memory you "just insert the disk."

S5 seemed to confuse the working memory with the disk memory as noted by the response of "erase files" during I2 when asked how to change memory. Too, during I3 the screen display was equated with working memory.

Possibly because of her computer background, S6 had a very good notion of memory. However, during I3 in response to the question, "Does 'doing a catalog' and looking at the disk contents change the memory?" she said, "Yes, because I think of memory as being what you are working with at the time. The list is what you are working with."

In summary, memory seems reasonably well learned. There are confusions between permanent and temporary memory, between memory and disk, and between memory and screen display. Generally the subjects improved considerably in their understanding of memory and their examples and explanations about memory across the course. The generalization by S6 of ordinary concepts of memory may need to be exploited. This is consistent with the suggestion of Mayer (1982) to use conceptual models for teaching programming.

Concepts: Command and Program. Commands are seen as specific instructions for the computer to do something. In addition to the tendency for students to subsume commands under the concept of data, some students did not want to admit that the commands in menus of applications software were commands; commands seem to be perceived as needing to be

more fundamental than menu items. During I3, S2 said that "it seems like only Logo has commands [e.g., FD, BK];" she seemed unable to apply the textbook definition that she stated. S3 consistently said that commands are "built in" to the machine or the program and come from the disk.

Program seemed the best understood of the five concepts. The only confusion in the comments of the students was that the document in a word processing environment or the records in a database environment were programs; subject S2 said this explicitly and S6 talked about programs and data for programs as if they were nearly the same concepts. This reinforces the observations in Study One.

Conclusions

Most obviously students do have misunderstandings about fundamental computing concepts. This should come as no surprise to anyone. The data of this study illustrate that the computer literacy instruction seemed to put a burden on students to generate models of understanding about computing. For example, since so little is said in the course about data, students must create a generalized notion of what data is; the notion that they have created is that of "anything you type in." This notion is a consistent generalization of the concept of data from other areas such as science and social studies. That is, in science experiments students generate data, and in social studies they go to the library to gather data. Hence, data is the product of their own efforts. In the computer environment what they do is type, so their notion of data is reasonably going

to be "anything I type in."

Study Three

The primary goal of this study was to probe further into the level of understanding of students enrolled in the same computer literacy course in which Study Two was conducted. At the time of this study, the course was taught on a Macintosh Plus network; the software included Microsoft Logo, Microsoft Works, and Microsoft BASIC.

Sample

Subjects were all students enrolled in the course in Spring 1987. Although 57 students completed the pretest, only 27 (mean age 25.4 years) also completed the posttest. (Participation at both stages was required to be voluntary by the University's Committee for the Protection of Human Subjects.) Similarly, 12 students initially volunteered to be interviewed, but only six completed both interviews. All interviewees were female; their mean age was 21.7 years.

Procedures

Five concepts were studied: command, data, file, language, and program. A 40-item test, given as both a pre- and posttest to the course, was developed by one of the experimenters; eight items were developed for each of the five concepts. The 40 items were also classified to measure understanding of examples of the concepts (10 items), attributes of the concepts (14 items), and analogies for the concepts (16 items).

Each of the six volunteers was interviewed twice; once about mid-way through the course (after Logo and word

processing instruction) and once at the end of the course. Each one-on-one interview began with questions much like those used in Study Two, after which the subject was asked to perform two hands-on activities with a Macintosh microcomputer. In the first interview these were (a) creating a Logo procedure to draw a rectangle and then saving and retrieving that procedure and (b) editing a letter in the word processor used in class. In the second interview these activities were (a) creating a database of three names and phone numbers, sorting that database alphabetically, and saving and loading the records and (b) writing a short BASIC program to print one's name 10 times, appropriately numbered 1 to 10. All interviews were audio taped, and transcripts were prepared from the tapes.

Results

Since many of the observations are similar to those presented for Study Two, only summaries of the observations in the two interviews will be presented. These are organized according to the five concepts studied.

Concept: Language. In I1 (that is, interview 1) the confusion about language ranged from a vague sense of its role in writing programs and establishing command syntax to clear confusion between program and file. (In part this may have been due to the "user friendly" nature of the Macintosh environment, but that will be discussed in detail later.) Subjects did not offer any analogies in their explanations; most comments dealt with the function and characteristics of language. Only two

subjects identified Logo as a language, one subject described Logo as a file, and one described it as a program.

In I2 the same confusions seemed to be present, with only two of the six subjects correctly identifying both Logo and BASIC as languages. Even these two, however, admitted to not knowing the difference between language, program, and file. One subject described Logo and BASIC as programs. The best description of language was "the type of words you can use." All subjects accessed BASIC successfully, but they were not all successful at completing the hands-on task.

Concept: Program. During I1 all subjects seemed to have a limited sense of program, though most talked in terms of a list of commands. There was confusion, however, between application programs and student-generated programs. The only analogy offered was that of a typewriter for the word processing program. Subjects relied on describing attributes of programs, with most of these descriptions referring to Logo rather than to the word processing program.

During I2, program was defined by five of the subjects as a set of commands. One of these five acknowledged the potential for data to reside in a program. All subjects seemed secure in knowing that a program could reside either in the RAM or on a disk, but only four were sure that these two things could happen simultaneously, acknowledging that programs are copied from disk to RAM rather than moved. Applications programs were typically defined in terms of their functions rather than as programs. Only one subject classified all three types of

application programs as programs. Although the use of analogies in discussing the concept of program was rare, five subjects used the typewriter analogy for the word processor. One subject compared spreadsheet formulas to algebra formulas; one subject stated that there were different kinds of formulas, such as "class average, student's average, . . ." One subject compared the database to the spreadsheet (in terms of locations for information), and one other subject compared the database to "an address book or an index." In the hands-on activities, subjects had great difficulty at creating a simple BASIC program (involving a FOR/NEXT loop), indicating poorly developed programming skills; indeed only two subjects succeeded.

Concept: Command. During I1 subjects tended to explain basic attributes or functions of commands; there were no analogies offered. All subjects characterized commands as "telling the computer to do something," and all recognized the need for proper syntax. Examples showed confusion between commands and data (e.g., FD 20 involves both a command and data). Only one subject reported menu items as commands. One subject said "commands are used to build programs." Subjects seemed to have only small repertoires of commands to use in completing the hands-on activities.

During I2, all subjects again provided a definition like "telling the computer to do something." One subject seemed to believe that commands could exist "on the screen" as well as in RAM and on disk. Subjects showed increased repertoires of

commands for word processing, possibly because of continued use of word processing throughout the course. Four of the six had great difficulty with the database activity, apparently because of a lack of understanding of the function of the commands in the database menus. Subjects also seemed not to recognize alternate commands for completing tasks; for example, using "SAVE AS . . ." to store an updated version of the current file, when "SAVE" would have done the same job faster and with fewer keystrokes. This lack of flexibility made the hands-on activities difficult for subjects.

Concept: Data. In I1, subjects seemed to generalize data as only information typed in from the keyboard. It was not clear, however, whether everything typed in would be classified by most subjects as data. Computer generated data, such as error messages, were universally not recognized as data. Two subjects said data was "information the computer already knows." Data was frequently referred to by specialized names; for example, numbers, names, and addresses. No analogies were offered, though examples of data, like letters for word processing, were discussed by the subjects.

During I2 a variety of definitions were offered, from "information" to "what the computer reads in a DATA statement" to "what you type in." Again, examples were given for specialized types of data, with little acknowledgement of any generalized notion. In the context of the database task, there seemed to be little confusion about what was the data (i.e., the names and phone numbers), possibly because these

were examples of the more specialized notions. Explanations about where data resides (e.g., on disk, in RAM) were vague and confused. All subjects agreed that data could be stored on disk but only three allowed data to be in RAM. Two subjects believed that data could be in the computer with the power off, and one other thought data could be on the screen.

Concept: File. In I1 file was confused both in terms of its location and its contents, though four subjects described a file as a place for storage. Subjects generally understood that a file was moved (rather than copied) when it was loaded into RAM. Two subjects thought that files were created when the computer was booted.

During I2 only three subjects could distinguish between (a) a file as a location on a disk and (b) the information stored in a file. No one was able to clearly explain that different kinds of information (e.g., BASIC program, word processing document) could be kept in a file. Three subjects stated that a file could reside both on a disk and in RAM simultaneously, with one of these believing that files exist "on the screen," and two others saying that files existed on the network. No analogies were offered for file.

Test Results

Analyses of covariance (with appropriate pretests as covariates) were conducted between the interviewed and non-interviewed subjects for the total posttest and for each of the post-subtests. Only one of the nine F-values (for the subtest on command) was significant; so the interviewees

appeared to be roughly representative of the entire sample. For the complete sample, the differences between posttest and pretest scores were significant at the .002 level for the total test (pretest mean = 13.4, posttest mean = 23.6) and for each of the subscales. This indicates that learning occurred as measured by each of these tests. The pretest and posttest reliabilities for the total test were .92 and .76, respectively. Of the posttest subscale scores for the five concepts, the command scale had a noticeable higher mean (6.3) than any of the other four scales (with means of 4.1 to 4.7). The examples subscale had a higher posttest mean (74%) than either the attributes subscale (51%) or the analogies subscale (54%).

Conclusions

Subjects made some progress during the course at using proper computing terminology, but their ability to clearly explain fundamental computing concepts did not seem to improve dramatically. On the basis of the interviews, the best understood concepts seemed to be command and program, and the worst understood concepts seemed to be data and file. This ordering is marginally consistent with the results of the tests.

Discussion

On the basis of the three studies it seems clear that students in computer literacy courses are not developing clear understandings of fundamental computing concepts. As prospective teachers, the subjects all demonstrated misunderstandings that could be easily passed on to their students. This was painfully clear during the interviews when

subjects were asked to verbally explain concepts. Yet, the hands-on tasks were generally completed. Computer literacy students may be confusing ability to perform a task with understanding of the underlying concepts. For people in the real world, this distinction may not be important, but for teachers it is critical. Teachers need to be able to identify misconceptions in their students' thinking so that these misconceptions can be corrected. The subjects in these studies clearly did not have this capability.

The experiences in interviewing subjects in Studies Two and Three suggest some potentially important differences between the two computing environments. The human/machine interfaces are quite different for Apple II and Macintosh microcomputers. Apple II software generally requires that the user interact through control characters typed in at the keyboard. Macintosh software generally allows the user to interact through the mouse and the pull-down menus that are displayed across the top of the screen. This is an important difference, since in the Macintosh environment, complete words are used in the pull-down menus to identify the functions that are to be performed. This provides constant reinforcement, in more-or-less natural language, of what is going to be done.

Too, in the initial menu for a Macintosh disk the files are all identified with icons. There is no obvious notational difference by which the novice user can distinguish between a file that contains a program (like Logo or Works) and a file that contains data for a program (like a letter for the word processor).

Clicking on a data file automatically causes the application program to be loaded, followed by the loading of the data file. In the Apple II environment, the application program must be loaded first, and then a search must be conducted to find the data file that is to be loaded. The user must perform both steps explicitly. The Macintosh system has the potential for creating a conceptual confusion in the user about what the difference is between a file containing a program and a file containing data for a program. Clicking once on either type of icon causes the application program to be loaded. The subjects in Study Three did not seem to distinguish between clicking on the application program (which they all did to access Logo) and clicking on a data file (which they all did to access the letter to edit).

In Study Three, it was also observed in the hands-on activities that subjects were not very efficient in their sequencing of keystrokes to accomplish some particular task. As noted earlier, all subjects used the SAVE AS instead of the SAVE command in the FILE menu to save the updated version of their current data. Four of the subjects used the CUT and PASTE commands to delete individual characters instead of simply positioning the cursor and backspacing. Two subjects also confused the disk drive with the network in terms of identifying where files are stored. All of these confusions have the potential for decreasing the usability of computing skills for these subjects and consequently for limiting the use that these prospective teachers might make of computing

power in teaching their future students. That is, if teachers believe that computers are not effective and efficient ways to learn, then they will be less likely to use computers with their students, and the quality of instruction for those students might suffer.

In terms of structuring computer literacy instruction, it seems wise to advise teachers to use more analogies to assist students in the developing of an accurate underlying conceptual base. Our subjects did not "naturally" use analogies in their explanations. We speculate that if they had had such analogies available, their explanations would have been more accurate and the limits of their understanding would have been more self-evident.

References

- Bowman, R. F., Jr. (1986). Computer literacy: A strategy for cultivating consensus. Technological Horizons in Education Journal, 13(10), 60-62.
- duBoulay, B. (1986). Some difficulties of learning to program. Journal of Educational Computing Research, 2, 57-73.
- Harrison, M., & Harrison, B. (1986). Developing numeration concepts and skills. Arithmetic Teacher, 33(6), 18-21, 60.
- Hawaii State Department of Education. (1985). Exploratory computer literacy curriculum guide. Grades 7-8 (Report No. RS-85-7792). Honolulu, HI: Office of Instructional Services.

- King, K. M. (1985). Evolution of the concept of computer literacy. Educom Bulletin, 20(3), 18-21.
- Mayer, R. E. (1982). Contributions of cognitive science and related research in learning to design computer literacy curricula. In R. J. Seidel, R. E. Anderson, & B. Hunter (Eds.), Computer literacy: Issues and directions for 1985 (pp. 129-159). New York: Academic Press.
- Osborne, R., & Wittrock, M. (1983). Learning science: A generative process. Science Education, 67, 489-508.
- Pea, R. D. (1986). Language-independent conceptual "bugs" in novice programming. Journal of Computing Educational Research, 2, 25-36.
- Pea, R. D., Soloway, E., & Spohrer, J. (1987). The buggy path to the development of programming expertise. Focus on Learning Problems in Mathematics, 9(2), 5-30.
- Posner, G. J., & Gertzog, W. A. (1982). The clinical interview and the measurement of conceptual change. Science Education, 66, 195-209.
- Quintero, A. H. (1986). Children's conceptual understanding of situations involving multiplication. Arithmetic Teacher, 33(5), 34-37.
- Sleeman, D., Putnam, R. T., Baxter, J., & Kuspa, L. (1986). Pascal and high school students: A study of errors. Journal of Educational Computing Research, 2, 5-23.
- Waugh, M. L., & Currier, D. (1986). Computer-based education: What we know and need to know. Journal of Computers in Mathematics and Science Teaching, 5(3), 13-15.

Figure 1

Final Examination Question (with errors), Study One

Below are subsets of the commands (listed in alphabetical order) in BASIC, Logo, and Bank Street Writer. Identify the commands from each set (if such commands exist) that accomplish each task.

BASIC: DELETE, GOSUB, GOTO, HOME, INPUT, LIST, NEW, PRINT, RUN

Logo: CLEARSCREEN, ERASE, ERASEFILE, HOME, POTS, PRINT, PRINTOUT, TO

BSW: CLEAR, COPY, DELETE, ERASE, MOVE, PRINT-FINAL, RETRIEVE

Task	BASIC	Logo	BSW
a. clear RAM only	HOME/NEW 1	blank 4 CS 2	CLEAR 17 ERASE 4 DELETE 1 PRINT-FINAL 1
b. clear screen only	blank 1	HOME 1 ERASE 1	CLEAR 9 ERASE 6 DELETE 2
c. execute the program (procedure) in RAM		PRINT 9 TO 8	PRINT-FINAL 10 RETRIEVE 3
d. call a subroutine	GOTO 1 LIST 1	TO 17 PRINTOUT 1	RETRIEVE 3 blank 2 COPY 1
e. list on the screen the code (commands) in RAM		POTS 13 PRINT 3 TO 1	RETRIEVE 3 COPY 1
f. remove a file from the disk	blank 8 PRINT 1	blank 2 PRINT 1	blank 5 ERASE 5 RETRIEVE 3 CLEAR 1

Figure 2

Mid-term Examination Question and Errors, Study One

Draw the design generated by the command, FLAGS 10.

```
TO BOX :SIDE
  REPEAT 4[FD :SIDE RT 90]
END
```

```
TO FLAG :X
  FD 10
  BOX :X
END
```

```
TO FLAGS :Y
  PU HOME CS PD
  FLAG :Y
  PU HOME
  LT 90 FD 50 RT 90 PD
  FLAG :Y + :Y
  HT
END
```

ErrorCount

flagpole errors

flagpole proportional to flag	6
flagpole shortened to accommodate larger flag	1
ignore flagpole	1

flag errors

interpret :Y + :Y as :Y	5
draw two flags instead of large flag	2
interpret :Y + :Y as 12	1
draw three flags with poles	1
attempted recursion	4
orientation errors	3

CONVENTIONAL SCIENCE AND STREET SCIENCE IN THE WEST INDIES

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Despite the spate of curriculum development in science education world-wide in the 1960s and 70s, there is a general awareness that 'something else' is needed in science classrooms - some change is necessary to promote the level of learning and conceptual understanding in children for which educators have been searching.

In keeping with this, over the past decade or so, the question of the kinds of background knowledge children bring with them to their science classes has been engaging the attention of science education researchers world-wide. There have been two lines of investigation into the problem. That with the longer, more detailed and structured research history, has focussed on examining children's understanding of specific concepts in science, for example, heat, energy, force, plant nutrition. Research groups such as the 'Children's Learning in Science' group at the University of Leeds and the 'Learning in Science' group at the University of Waikato have concentrated on this aspect. Several studies have also been described in the literature (see for example, Andersson, 1980 - boiling point; Tiberghien, 1980 - heat; Viennot, 1980 - dynamics; Solomon, 1983 - energy; Osborne and Cosgrove, 1983 - change of state of water; Aguirre and Erickson, 1984 - vector characteristics; Fisher, 1985 - amino acids and translation; Griffiths and Grant,

1985 - food webs; Cros *et al.*, 1986 - constituents of matter, acids and bases; Terry and Jones, 1986 - Newton's third law).

The second line of investigation has dealt with children's background experiences of a different nature. Instead of concentrating on specific conventional science concepts, these attempts in science education research have been seeking to document and describe those cultural beliefs of children that are likely to influence learning in science. The intent is to try to gain some insight into children's frame of reference in science. This might elucidate the origins of the conceptions brought into the formal school, many of which have been revealed by the first line of investigation.

Champagne (1986) uses the term ethno-science to refer to 'behaviours and theories that have evolved informally within cultures to explain and predict natural phenomena' (p 14), and advocates a reconceptualization of science teaching as a modification of ethno-science.

Whether one agrees with this viewpoint or not, it would seem that a clearer understanding of these cultural influences is needed -

- to provide teachers with additional information which might help them to better understand the children they teach

- to facilitate some prediction of what might be expected to surface in the classrooms in a particular context
- to identify concepts in science which children might find difficult to understand because of conflicting cultural beliefs.

PURPOSE OF THE STUDY

The Caribbean nations of Jamaica and Trinidad and Tobago, separated by a thousand miles of sea, are both former colonies of European powers, with Britain being the last colonizer in each case. Jamaica gained independence on August 6, 1972 and Trinidad and Tobago followed on August 31 of the same year. Both countries have a legacy of African slavery and the system of East Indian indentureship. In addition, there are other groups like the Chinese, Jews and Lebanese which have contributed to the diverse but similar cultural backgrounds in these islands, and to their consequent rich store of folklore.

One of us (Glasgow 1986) has looked at the question of local beliefs in Jamaican fifteen year olds. The thesis was to regard a willingness to accept as truth selected sayings (against logical evidence to the contrary) as an expression of a non-questioning attitude - a stance which is the reverse of that encouraged by conventional science. No attempt was made in that study to analyse the sample of

beliefs used for the concepts they contained, but scores on the true/false scale used suggested that children were highly committed to these beliefs, despite the fact that they had all been exposed to three years of an integrated science programme. (Total possible score signifying rejection of all sayings = 20; mean = 12.733; S.D. = 4.388; N = 643).

The other author (George 1986a), in describing the science-related backgrounds of students in Trinidad and Tobago, has attempted to distinguish between 'superstitions' and what she refers to as 'street science'. The latter she describes as "those social customs and beliefs that deal with the same content areas that are dealt with in conventional science but which sometimes offer different explanations to those offered in conventional science" (p 1). Content areas in these cultural beliefs that fall outside of the domain of conventional science (e.g. luck, spirits) are not regarded as street science, but rather as superstitions. In making this distinction, George goes beyond the definition of ethno-science given by Champagne (1986) where no attempt is made to sub-divide the 'behaviours and theories' to which reference is made.

George (1986b) examined the street science beliefs held by a sample of lower ability 15 year old students in Trinidad and Tobago (N = 223), who, like their Jamaican counterparts, had all been previously exposed to a three-

year integrated science programme. She found that on an instrument containing 33 street science statements, matched with a True/False/Don't Know response scale, more than one half of the sample chose the response that is not sanctioned by conventional science for 73 per cent of the statements. This study was limited to lower ability students so no claims can be made on the basis of these results about the wider population of students in Trinidad and Tobago. The results do indicate, however, that there appears to be a high degree of commitment to street science by at least one segment of the school population.

This preliminary work encouraged us to carry out a more detailed, though still exploratory investigation prompted by several concerns:

- 1) to gain a deeper knowledge and some understanding of the meaning of the beliefs themselves
- 2) to identify probable specific implications of these beliefs for science in the classroom
- 3) on a wider scale, eventually to document those practices which are advantageous to keep, in the face of strong extra-cultural influences for change.

This paper addresses itself to the first concern, and to suggesting a link or bridge with the second by analysing a collection of local sayings, to abstract the main concepts/principles they contain, and to compare these with concepts/principles in conventional science. It is hoped

that the knowledge gained from this exercise will give clearer insights into the science related ideas which children in our society might hold, thereby providing a basis for a structured probing of the second concern.

DOCUMENTING THE BELIEFS

Through interviews and questionnaires a number of local cultural beliefs was collected from a variety of sources - from medical personnel, elderly citizens, practising small farmers, teachers, school children and their parents, science educators, university lecturers researching bush medicines and regional creole and oral traditions. Both authors also have a wide repertoire of these sayings as a result of living and working in several areas of these islands. Additionally source documents, viz, reports of the regional Caribbean Food and Nutrition Institute (CFNI) and the Jamaican Scientific Research Council (SRC) provided further information. These institutions have, for many years, recorded beliefs within the scope of their concerns (chiefly nutrition). No claims for the comprehensiveness of this collection is made by the authors since it is recognized that such a claim could only be substantiated by several years of study. Nevertheless, this listing does represent the first attempt in the West Indies to document and analyse a sample of these sayings as they apply to the study of science.

The entire listing, was divided into four categories (after George 1986a).

Category 1 Those following conventional science principles
e.g. If cooking oil is poured in the water
when green figs (bananas) are being boiled,
the green figs will not stain the pot.

Category 2 Those in which a conventional science explanation seems likely, but is not yet available.
e.g. 'Vervine (*Stachytarpheta jamaicensis*) is good for worms'. (This plant is known to have pharmacological properties, but appropriate usage has not been verified)

Category 3 Those presenting a distorted view of conventional science

Category 4 Those in which there is no conventional science evidence to support the claim.

The beliefs/saying grouped under Categories 3 and 4 represent the body of street science which will form the bases for the analyses in this paper. A combined total of 198 sayings belonging to these two categories was collected - 82 of them existing in Jamaica only, 54 of them existing in Trinidad and Tobago only and 62 of them being common to both Jamaica and Trinidad and Tobago.

Content patterns emerging from the raw data suggested that sayings could be subsumed under the following topic

areas:

- | | |
|---|---------------------------------------|
| - Animal reproduction (excluding man) | - Lunar effects |
| - Changes in the physical environment | - Menstruation |
| - Child rearing practices and injunctions | - Plant/animal behaviour |
| - Food and nutrition | - Plant growth and reproduction |
| - Health | - Pregnancy, birth and postnatal care |
| - Household practices | - Properties of dew |
| - Human fertility and reproduction | - Temperature changes |

Not surprisingly, the greater number of street science beliefs seem to deal with nutrition, health, reproduction and child care and food production. These beliefs, it must be remembered, have helped to dictate a code of behaviours by which a people have survived.

Abstraction of the main principles from the various content areas has revealed that there appear to be four main themes running throughout the body of beliefs and across content contexts:

1. The whole system of cause and effect is simple, immediate and direct. There is no intervention of physical and/or physiological processes between the two.
2. Linked also into the cause/effect system seems to be the ready transfer of experiences and ideas/explanations

across contexts. Experiences with inanimate objects are transferred to human beings. Another facet of this transfer is the belief that the physical and emotional state of human beings can affect productivity and form in the biological world.

3. There are no shades of grey in street science. Everything is either black or white. Put another way, street science generalizes far more readily than conventional science.
4. Special powers/characteristics are attributed to particular conditions/objects:

[a] Femaleness: The female of the species is a peculiar being. Thus it is girls who must not climb fruit trees; it is the menstruating female whose activities are likely to end in failure; it is the pregnant woman who can improve plant productivity.

[b] The moon: This celestial body is extremely important in the scheme of life. It influences growth, reproduction and productivity in the biological world.

THE MAIN THEMES

CAUSE AND EFFECT

The directness posited in the relationship between cause and effect is perhaps the most commonly observed

characteristic in the sample of street science analysed. It is evident both in those sayings which represent distortions of conventional science and in those where the explanations offered are different from those of conventional science. For example, child rearing and diet injunctions dictate that certain behaviours and food have a direct causal effect on health, growth and development. This principle is reiterated time and again in various sayings. For many of these sayings, intervening and explanatory processes which could contribute to their interpretation can be identified in the conventional science system.

There seems, for example, to be a basic recognition that foods contribute differently in ways which are each necessary for the proper metabolic functioning of the body. Underlying the 'gain of intelligence' attached to eating fish or drinking much milk, is probably the realization that these are foods which will help proper development. Similarly, the supposedly increased speed with which babies acquire facility of speech if 'nightingale soup' is a part of the diet, would appear to be based on an appreciation of the value of certain foods for infants. These facts would in conventional science be explained in terms of the high protein content of animal flesh.

The code advising on means to enhance virility and fertility in the male, suggests a diet with heavy inputs of oysters, 'pacro-water', sea (Irish) moss. Again, these are

high protein foods. On the other hand, there is the admonition that too many acidic drinks will adversely affect a man's reproductive ability, a claim that has no base in conventional science. Could it be that the corrosive property of citric acid is thought to persist even after passage through the digestive system and absorption into the blood stream?

In a consideration of factors governing weight gain/loss, sayings like 'milk is fattening', and 'eating citrus casues weight loss' seem to be indications of a recognition of the relative energy value of these foods. Where, however, street science contends that it is the food itself which contributes to weight gain or loss, conventional science stresses the quantities and energy value of foods consumed.

Again the belief that drinking cocoa/chocolate results in rotting of the bones may be explained in conventional science by the necessity of calcium for bone formation. Cocoa (factory processed) and chocolate (home processed) are both prepared from the seeds of the cacao plant, and have high concentrations of ethanedioic acid, which would tend to take calcium out of circulation in the body by converting it to insoluble calcium ethanedioate.

The admonition not to eat 'rice, fresh fish or avocado pears' if one wants a wound to heal (they cause 'bad blood'), is another example of the direct effect of diet on body

processes which has surfaced in street science. The term 'bad blood' is used to mean 'blood lacking in iron', and the saying may have some background in the realization that for quick healing, blood properties should be at a peak.

Pregnant women are advised to eat plenty of ochroes. Cooked ochroes are 'slippery', therefore eating much of this food will make delivery easier for the expectant mother. 'Too much ice delays the passing of the placenta' - the inference here is probably linked with the 'cold' of ice. Drinking milk (which is white) makes the baby 'light' in colour. In other words, it is postulated in street science that the physical characteristics of these foods directly affect the process of child birth-interpretations which are different from those which would be offered by conventional science.

In all of these cases which deal with diet, no cognizance seems to be taken of the processes of digestion and assimilation which intervene between eating and any effects the components of various foods might have on body systems or processes.

The belief that 'labour will be long' unless the pregnant woman 'has small portions of food' is probably a recognition of the fact that in pregnancy, a careful diet is necessary to ensure that the baby does not become too large for easy delivery. Again the intervening concept that diet affects the size of the child, which in turn may help

to determine how difficult a birth is, is missing from the street science idiom.

Illustrations of this direct cause/effect system are not confined to diet-related pronouncements. Many mammals use the sense of smell in the identification of their young, and are to be seen sniffing at their tails. The street science warning that 'touching the tail of a goat kid will cause the mother to kill it' is probably an extension of this conventional science principle. The directness of the result in street science, however, omits the intervening explanation that obliterating or confusing the scent of the young may cause the mother to reject it before it can fend for itself, thus eventually resulting in its death.

On the other hand, the very direct effects of holding a guinea pig by its tail ('the eyes will drop out'), and of sleeping with moonlight shining on one's face ('the face will become swollen') are explanations outside the realm of conventional science.

In street science, dew is thought to have therapeutic properties. 'Dew gathered from leaves and used to bathe sore eyes makes them better'; one is also encouraged to put wilting plants in the dew to revive them. In each of these injunctions, a link which might explain the effect is missing in street science. The formation of dew is

explained in conventional science as the condensation of excess water vapour in the atmosphere. Provided that this condensation process occurs on a clean surface, the resulting water will be pure. Perhaps it is the soothing effect of fairly pure water, free from irritants, that 'makes the eyes better'. Similarly, the effect on the plant is likely to be due as much to the reduced temperature of the air at night, discouraging cuticular transpiration, combined with stomatal closure, as to any moisture which might be supplied by 'dew'.

Another example of this direct effect is the belief that sudden temperature changes, however mild, adversely affect the human body, resulting in illnesses such as 'colds' and fevers. 'Colds' in street science is an all-embracing term covering symptoms of increased mucus secretions in the upper respiratory tract. Street science acknowledges, with conventional science, that these symptoms may sometimes be brought on by temperature changes, as in rhinitis. The viral infection which causes the common cold is, however, totally missing from the street science idiom.

TRANSFER OF EXPERIENCES AND EXPLANATIONS

There are numerous street science admonitions that caution about the practices/environmental conditions that are likely to cause colds and fevers. Thus, for example, one is advised not to bathe after working in the sun, cook-

ing or ironing, until one has 'cooled off'. Implicit in these statements is the idea that the temperature of the human body can be changed appreciably by an external source of heat. As well, the fact that there is usually the admonition that one should 'cool off' before being exposed to a cooler temperature, suggests that it is the difference between body temperature and the ambient temperature that is thought to be critical. In this regard, street science seems to be transferring the principles that govern heat flow between inanimate objects and their surroundings to human beings in their entirety, without giving any cognizance to the principle of homeothermy.

Street science does not seem to include the principle that latent heat of vaporization is drawn from the human skin whenever a cooling effect is felt. Instead, the street science principle is that the cooling effect is due solely to the lower temperature of the medium in which the individual is. Thus, water in a container feels cool (to the skin) because it is at a lower temperature than the surrounding air and the room in which a fan is blowing feels cool because the temperature in the room is lower than if there were no fan in it. Here again, it would seem that the process of heat flow as it relates to inanimate objects and/or poikilotherms is also being applied to human beings.

The transmission of yield and phenotypic effects to plant life as a result of man's physical and emotional state or certain modes of behaviour, has no parallel in conventional science. The following are examples of some of these beliefs. 'Planting yams when one is hungry makes the tubers hollow'. When the 'young' plant seeds they will not 'bear well', but if a 'lazy man' plants anything it will 'bear better'. Using the fingers only to plant yams will somehow affect the expression of the genes, and the new tubers formed 'will be just like the fingers' (from a marketing point of view the tubers are better long and straight).

Street science suggests that even after plants have reached the reproductive stage, man's behaviours may still affect yield. For example, 'counting or pointing to the fruit on a vine will cause them to drop off'. 'A single pod should not be picked from an ackee (*Blighia sapida*) tree; the others will fall off'.

Another group of beliefs states that a pregnant woman should not see or commiserate with deformity, or even have unusual cravings for foods, for fear that her child will be deformed. She should not 'look upwards' too often, or 'drink from a bottle or gourd' or her baby will be born with 'cast' (crossed) eyes. There are no 'companions' to these ideas in conventional science; but, as with plant form, these are non-genetic explanations offered for physical

defects in the child. Conventional science now holds that the passing on of traits from parent to offspring is determined by the genes. Is there, however, in these street science beliefs something reminiscent of the once held "scientific" view of the transmission of acquired characters?

GENERALIZATIONS

One of the fundamental characteristics of conventional science is the necessity for sound evidence to substantiate claims. Casual or spasmodic observations are not enough. As a consequence, generalizations are made only when particular patterns persist after repeated observations. Even so, these generalizations can change with new evidence. These stringent criteria do not seem to apply to street science and there are many examples of instances where street science seems to generalize more readily than conventional science.

Several of the admonitions that contain generalizations deal with the natural environment. For example, minor earth tremors are a common occurrence in the West Indies, but major earthquakes are not at all common. Consequently, the existence of a street science statement that attempts to describe atmospheric conditions that precede an earthquake ('if there is a spell of very hot days, an earthquake is likely to occur') indicates that generalizations are probably being made on the basis of limited observations.

On the other hand, conventional science would insist that there is no truth whatever in the street science claim. Instead, conventional science teaches that whereas the frequency of earthquakes in a particular area over a specified period of time may be predicted from an analysis of earthquake patterns in that area, it is almost impossible to predict exactly when an earthquake will occur.

One popular street science admonition is that all mirrors should be covered during thunderstorms to prevent lightning bouncing off the mirrors and causing death. The generalizations implicit in this admonition may perhaps be described best in the form of a syllogism:

Lightning looks like light

Light bounces off plane mirrors

Therefore lightning can bounce off plane mirrors

Lightning causes death

Therefore lightning bouncing off plane mirrors
will cause death.

The generalizations are clear. Lightning looks like light and therefore is like light in all respects. Lightning has caused death in the past and therefore will cause death in the future - even though the conditions may not be the same.

Insects are particularly abundant and active when the moon is shining, according to street science. Conventional

science contends that there is no proof of this. In fact, conventional science claims that nocturnal insects are less conspicuous when the moon is full or when it is waxing (Kirkpatrick and Simmonds, 1958). Consequently, conventional science would dismiss the street science admonitions of not cutting bamboos or planting crops when the moon is shining (for fear of attack by insects) as being without substance. One wonders though whether the street science beliefs about the preponderance of insects at this time are not due to the fact that these creatures will be more visible to man during periods of moonlight, given the fact that in many rural areas where agriculture is practised, there is sometimes no electricity. This would explain why the phenomenon is linked with moon phases. In any event, street science does not seem to have considered any other variables that might be operating in this situation.

The street science theory regarding the formation of dew is another example of a willingness to generalize. Dew and rain are similar in that they are forms of water. Since rain falls, then dew also 'falls'. Thus, one is advised to cover babies' heads outdoors after nightfall to prevent dew from 'falling' on their heads and causing sickness.

The belief that 'burning land in preparation for planting will result in good yields' is perhaps associated with the knowledge that ash is a good fertilizer. Street science, however, ignores the loss of flora and fauna, the

soil erosion and consequent loss of nutrients promoted by this practice. Perhaps, originally, the practice arose out of the necessity to survive - to clear land for food, and protect oneself from poisonous/irritating bushes and animals by the quickest method. Now it has become a general prescription for productivity.

Examples of the ways in which street science tends to generalize far more readily than conventional science are not limited to street science statements that deal with the natural environment. Some statements that deal with food and nutrition also seem to exemplify this tendency. Thus, certain combinations of foods (for example, ripe bananas and rum, ripe bananas and butter, cornmeal and rum) are thought to be lethal. Could these admonitions have resulted because of isolated cases of death after eating these combinations of foods without any investigation into the other variables that may have been involved?

Children in these islands are often encouraged to eat carrots in abundance to ensure that they have good eyesight. Conventional science on the other hand teaches that carotene in yellow foods is a precursor of Vitamin A which is needed for the effective functioning of certain cells only in the eye - the retinal rods which allow for vision in dim light. Street science also generalizes by claiming that 'food that has been kept in the refrigerator is not as nutritious as freshly cooked food'. Conventional science is more cautious

in stating that the loss in nutrient value of refrigerated food depends on factors such as how fresh the food was when refrigerated, the temperature at which it is stored, the method of storage and the period of refrigeration.

According to the local beliefs, one should not eat certain foods (for example cucumbers, ripe bananas, acid fruits) after nightfall, as digesting them will be difficult. Again here, street science is generalizing more readily than conventional science. According to the latter, whether or not one suffers from indigestion after eating certain foods (after nightfall or not) will depend on individual tolerance for these foods. What is not easily digested by one individual may present no problems to another. What capacity does nightfall per se have to influence digestion? Is this perhaps an oblique reference to the lower basal metabolism attendant on sleep, through the association of the latter with nightfall, an association which might be stronger in a rural agricultural setting?

Acid fruits come up for further mention in street science admonitions to menstruating females. Taken during the menstrual period, these fruits are said to cause illness. The belief exemplifies, not only the direct effect of food on body processes discussed earlier, but perhaps, as well, the greater readiness of street science to generalize. Whereas conventional science would explain any observed illness in menstruating females after eating acid fruits in

terms of tolerance levels or other variables pertaining to the particular situation, street science is quite prescriptive in its assertion that these foods will cause illness at this time.

THE ASCRIPTION OF SPECIAL POWERS/CHARACTERISTICS

The foci for this theme in the beliefs analysed are the female human being and the moon. The moon is portrayed as affecting several biological processes. It is thought to influence plant growth and productivity, the growth of hair follicles, the time at which babies are born, and the activity and preponderance of nocturnal insects (discussed earlier) among other things.

The female human being, is, in very many instances, presented in a rather negative light. The state of 'femaleness' is described as being almost akin to a curse, especially in its association with menstruation. During this process, the female is advised not to bathe for fear of illness; not to bake cakes, as they will not 'rise'; not to pick fruits from trees since the fruits from those trees will be 'sour' to the taste in the future.

Curiously, however, the pregnant woman is regarded in an entirely different light. It would seem that the whole aura of pregnancy and everything connected with it, are regarded as harbingers of 'plenty', of productivity.

Should a pregnant woman plant a pumpkin vine or walk over one, it will 'bear well'. Planting the umbilical cord under a coconut tree ensures its productivity. One can understand the association of pregnancy etc. with productivity, but one wonders perhaps whether, as suggested by Miller (1986) in her resume on environmental education in Jamaica, the custom of planting the umbilical cord at the base of a tree does not also serve the purpose of conserving the environment both aesthetically, and from the point of view of availability of food and maintenance of the oxygen cycle. [Incidentally this custom also has cultural connotations of identity - "My origins are where my navel string is buried".]

All of these street science principles that refer to the moon or to 'femaleness' represent explanations which are completely outside the realm of conventional science.

CONCLUSION

From the foregoing consideration of what appear to be the main emphases or guiding principles within the body of street science knowledge analysed, some tentative suggestions as to possible implications for science in the classroom may be offered.

Acculturation in a situation which promulgates the syndromes of immediacy and directness in the cause and effect system, is likely to make it more difficult for children

to conceptualize the notion of variables with separate and interactive effects - a principle which is central to conventional science. Could the difficulty inherent in this 'mental switch' be the true basis of the classroom question with which science teachers in our society are familiar, despite their best efforts, 'Miss/Sir what is the conclusion?'

The characteristic tentativeness of science may not be easily appreciated where one is accustomed to ready generalizations. The importance of keen observation, and the repetitiveness needed to establish the credibility of empirical evidence are perceptions which might not at all come easily to the child. In any case, no 'observations' are value-free.

The ability to transfer ideas across contexts would be advantageous in the classroom if the rules governing the situations in which the transfer is valid are known and understood. A conflict is likely to arise, however, for students with a West Indian street science background, in that either these rules do not exist, or else they are not made explicit.

Ascribing special powers to chosen objects/conditions is not the preserve of street science. This is a style of thinking which would be reinforced in the tenets of faith in any religion - and ours is a very religious society. Could this manifest itself in a reluctance to adopt the

questioning stance espoused in the value system of conventional western-style science? Is this one of the sources of the inability of many students to formulate working hypotheses?

What we are saying is that a system advancing direct effects, ready generalizations and acceptance reflects an entirely different, and sometimes contrary (though not to be regarded as necessarily wrong) set of values to one in which the interaction of variables, tentativeness and a questioning attitude are points of stress. Further, this fact has to be recognized in the way classroom science is approached in our cultural context.

REFERENCES

- Aguirre, J., & Erickson, G. (1984) Students' conceptions about the vector characteristics of three physical concepts. Journal of Research in Science Teaching, 21 (5), 439-457.
- Andersson, B. (1980) Some aspects of children's understanding of boiling point. In W.F. Archenhold et al (Eds.), Cognitive development research in science and mathematics, (pp 252-260). Leeds: University of Leeds.
- Champagne, A. (1986) Children's ethno-science: an instructional perspective. In J. Gallagher and G. Dawson, (Eds.), Science education and cultural environments in the Americas, (pp 14-19). National Science Teachers' Association.
- Cros, D. et al (1986) Conceptions of first year university students of the constituents of matter and the notions of acids and bases. European Journal of Science Education, 8 (3), 305-313.
- Fisher, K. (1985) A misconception in Biology: Amino acids and translation. Journal of Research in Science Teaching, 22 (1), 53-62.
- George, J. (1986a) "Street Science" in Trinidad and Tobago: Analysis and implications for teaching conventional science. In P. Abder, (Ed.), Science education research in Latin America and the Caribbean, (pp 252-265). Trinidad: The University of the West Indies.
- . (1986b) "Street Science" - An analysis of science-related social beliefs of secondary school students in Trinidad and Tobago, Unpublished M.Ed. thesis, Queen's University at Kingston.
- Glasgow, J. (1986) Science education and superstition. Torch, 29, 1-11, Ministry of Education, Jamaica.
- Griffiths, A., & Grant, B. (1985) High school students' misconceptions of food webs: Identification of a learning hierarchy and related misconceptions. Journal of Research in Science Teaching, 22 (5), 421-436.
- Kirkpatrick, T.W. & Simmonds, N.W. (1958) Bamboo borers and the moon! Tropical Agriculture, 35 (4) 229-231.
- Miller, B. (1986) Environmental education. Unpublished paper prepared for the Country Environment Profile, National Resource Conservation Division, Ministry of Agriculture, Jamaica. 28 pp.
- Osborne, R., & Cosgrove, M. (1983) Children's conceptions of the changes of state of water. Journal of Research in Science Teaching, 20 (9), 825-838.
- Solomon, J. (1983) Messy, contradictory and obstinately persistent: A study of children's out-of-school ideas about energy. School Science Review, 65 (231), 225-229.
- Terry, C., & Jones, C. (1986) Alternative frameworks: Newton's Third Law and conceptual change. European Journal of Science Education, 8 (3), 291-298.
- Tiberghien, A. (1980) Modes and conditions of learning of some aspects of the concept of heat. In W.F. Archenhold et al, (Eds.), Cognitive development research in science and mathematics, (pp 288-309). Leeds: University of Leeds.
- Viennot, L. (1980) Spontaneous reasoning in elementary dynamics. In W.F. Archenhold et al (Eds.), Cognitive development research in science and mathematics, (pp 273-274). Leeds: University of Leeds.

Changing the Meaning of Experience:
Empowering Teachers and Students
Through Vee Diagrams And Principles of Educating
To Reduce Misconceptions In Science and Mathematics.
A Mode of Reform

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Introduction

Vee diagramming (see Figure 2) is a way to represent the dozen or so major epistemic elements arrayed around a Vee. Most scientists and mathematicians recognize the relevance of epistemic elements such as "theory," "concept," "event/object," "fact," and "knowledge claim." Students (and their teachers) can be taught in a brief period of time to name these epistemic elements and to see the connections between elements. Students, then, begin to conceive the structure of knowledge (structure elements and their relations to each other). Misconceptions can be located at the connections between epistemic elements. It is a faulty relation between pieces of the structure of knowledge that permits misconceptions to persist so strongly. The remedy then is to help both teachers and students to reconstruct prior knowledge. The Vee diagram analysis technic helps learners to move between elements--up and down, across, and between elements. This process of reconstruction of claims to knowledge is a primary learning process.

Part I

To educate, in my view, is to change the meaning of experience. Can we do it? Is educational reform possible?

Yes, we can change and reduce misconceptions.

The most recent evidence of change in science educating I have read is a Ph.D. dissertation study¹ completed at Cornell July, 1987 by John Feldsine. (Cf. Proceedings paper.) He started out here in 1980. He was and still is a chemistry

teacher of General Chemistry's first semester course at community college level. He focused only on introducing concept mapping to his students of chemistry. Seven years later he is still using the technics and teaching chemistry. For this paper the significant facts show how he migrated into teaching most of the other elements on the Vee diagram. In several cases his students were self-empowered to correct their scientific misconceptions. Such empowerment, to the point of self-educating, is, for me, as stated in my book, Educating, the end of education. Feldsine successfully managed to help make truly educative events happen in his chemistry classes. His practices--both of educating and doing research on educating--were governed by the same set of congruent theories. Thus, my first major point is to suggest that theories of educating supply practical solutions to the multiple problems of misconceptions in science and mathematics. New practices, and new concepts, come from new thinking theory stimulates.

In mathematics I will cite the study of Karoline Fuata'i.² She taught the Vee heuristic to Form Five (grade eleven) students in Western Samoa (education there is governed through New Zealand by the British colonial model). Karoline was able to introduce Vee diagram analysis to two of her classes, and to get these students to use these ideas. At the end of one semester, her students using these new ideas were able to solve novel problems in mathematics. Her other students could not. I cannot give here the whole story, but one major and common misconception about secondary math states that there is one correct procedure and one right answer. Students who get math this way cannot solve novel problems. The one right answer syndrome is a misconception. There are many ways to solve math problems.

My second major point is to suggest that educational epistemology also supplies solutions to problems. By understanding the structure of knowledge of subject matters (mathematics, chemistry), students, teachers, and researchers

have a mode of knowing that helps reduce misconceptions. Put differently, educational epistemology is an important key to a complex and daunting array of seemingly separate problems of misconceptions. See the Proceedings 187 papers.³

Educational epistemology is not sufficient, however. We need to coordinate it with theories of educating and to bring in explicitly Principles of Educating. I organize principles into the four commonplaces: teaching, learning, curriculum, and governance. Or, as I have started to label it: TLC plus G. (If you are an administrator, you might prefer G+TLC.) The first principle states that all four of these commonplaces must be considered together. No good reform of either educating or schooling will occur by just researching one of these four. For example, the psychological scientific studies of learning tell us almost nothing about teaching, curriculum, or governance. The 100-year search for scientific laws of human learning is an elaborate and complex history of failure. There are no laws of learning of the sort found in thermodynamics (say, the important second law). I generalize from this history of failure in social science research to say that I believe the natural science model of research is a poor choice for social and educational research.

Here, then, is another misconception, located in the philosophy of science. It is easy to see but difficult to change the fact that science and math professors and other teachers who use the dominant epistemology model of their subject matter to study educating are going to fail to find out much about educating. Our studies of the structure of knowledge of educational research give us evidence of what is wrong and a key to needed changes. Here the key is to pay attention first of all to events of educating themselves. We begin with educative events of TLC+G. Not with Science. Or Math. Nor the Epistemologies or Philosophies of Science or Mathematics.

To the extent you can accept this starting point, then the next step is to take a look at some Principles of Educating. I look at some issues with the help of a new study by educational historian David K. Cohen.⁴ Professor Cohen of Michigan State University has not published this work yet, but a book is forthcoming. I interpret Professor Cohen's historical analysis as a study of change. His study contrasts the conventional, perduring, unchanging patterns of schooling [from 19th century to date] with the ad hoc patterns of reform efforts. Most reforms fail. Most reforms in our field fail to change much. In Figure 1, I present a table partly inspired by Cohen's work, and based on our years of study here at Cornell.

<u>Conventional</u> (80%)	<u>Constructivist</u> (20%)
<u>Teaching:</u>	
Teaching is Telling.	Teaching is achieving shared meaning. Negotiating meaning to congruence.
<u>Learning:</u>	
Learner is obedient. Learner will learn what is taught.	Learner responsible. Learning is idiosyncratic.
<u>Curriculum:</u>	
Given. Fixed.	Emergent, constructed.
<u>Governance:</u>	
Make system work to serve the system.	Make system serve people. (Foxfire is an example of reform within the system.)

Figure 1. Contrasting Views of Practices in Education.

I realize, of course, these simple sentences serve only to sketch a contrast. They do not explain why these two patterns exist. It is my generalization (not Cohen's) that 80% of the time 80% of our schooling practices are the conventional ones. But this generalization should surprise no one. Indeed, it is almost a tautology: the conventional

is conventional. Custom is customary. The dominant dominates. The schooling system systematizes. I feel somewhat in the position of a man (or woman) who suddenly perceives patriarchy as dominant. Or perhaps a genius dolphin perceiving water. The familiar surround is difficult to perceive; we just live it. The conventional is dominant.

Can we change? Is reform even possible? Will misconceptions about educating persist as dominantly as those about science and mathematics? I am an optimist. I must be an optimist to be an educator: I believe events change, and I can help them change for the better. In Part II I will discuss change, what it is that changes, how to change misconceptions, and what principles of educating we can use to make constructive reform in schooling and educating.

Part II

Vee diagramming is a way to represent the dozen or so major epistemic elements arrayed around a Vee. Most scientists and mathematicians recognize the relevance of epistemic elements such as "theory," "method," "concept," "event/object," "fact," and "knowledge claim." Students (and their teachers) can be taught in a brief period of time to name these epistemic elements and to see the connections between elements.

Figure 2 shows an array of epistemic elements. One thing to note is the multiple interrelations possible. Another thing is to imagine these elements occupy different spaces in intellectual structure. Further, some elements change much more quickly, easily, and frequently than other elements. Finally, it is important to note that the construction of relations between concepts-events-facts is the priority construction. If these connections are not well woven together, the further elaborations at higher levels on the Vee are very likely to be spurious.

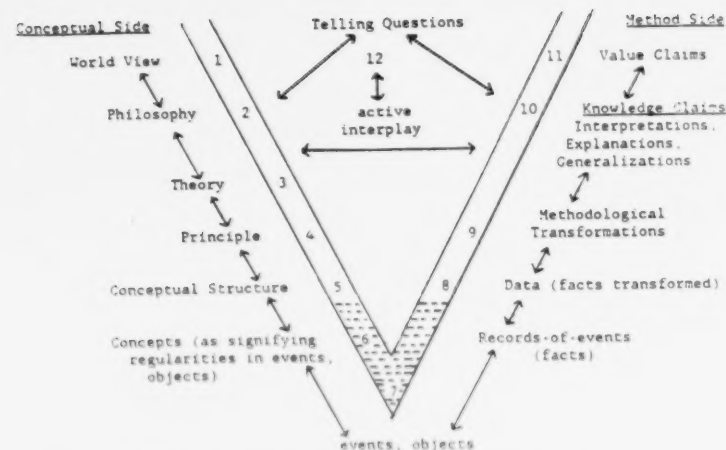


Figure 2 The Vee Heuristic as a Representation of the Structure of Knowledge. A Dozen Epistemic Elements

The Vee diagram heuristic has served very well as an heuristic. It has helped us disattach from accepted beliefs, to attach imaginatively to a set of separate new ideas, and to reattach to phenomena of educating. It has helped us "think otherwise." Somewhere in Educating⁵ I write that any heuristic is a crutch--helpful in doing things you normally cannot do. Further, once you learn how to do these new, non-normal activities, you can look forward to discarding the crutch. In my intellectual progress, I am getting to that point! Of discarding the heuristic. I am now confident that Vee diagram analysis is a real mode of work. It is as reliable and valid as any instrument of educational inquiry. Its meta-knowledge is real knowledge. I am happy to support Jerome Bruner's advice given to an overflow audience (1985) of AERA researchers: "Go Meta!!" The Vee diagram presents meta-knowledge, i.e., knowledge about knowledge.

Figure 3 shows another version of the Vee diagram. This version was done by Bernardo Buchweitz⁶ for his Cornell PhD dissertation in physics education. Professor Walter Wesley, also a physics teacher, uses this version in his paper

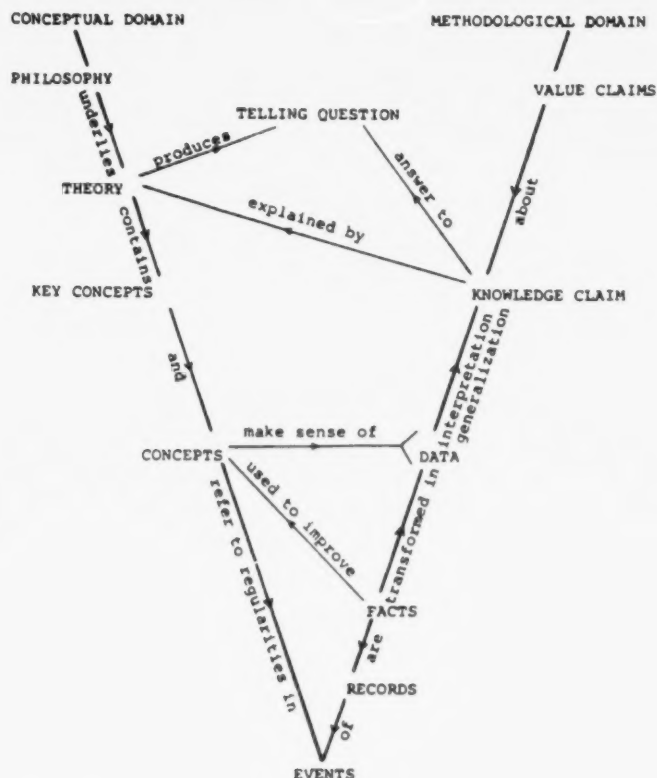


Figure 3. The epistemological vee. Some parts and relationships among the parts of the structure of knowledge (after Gowin, 1981).

published in these Proceedings. This diagram puts labels on the lines connecting epistemic elements, very much as we do with concept maps to connect concepts. It is a good Vee to use to introduce naive students to the idea that knowledge has structure and that the elements of knowledge structure have specific tests. For example, the test for "theory," coherence, is not the same test as the test for "method," following a procedure reliably. The idea that facts are records of events requires us to judge that (a) events did occur, (b) records were made, and (c) records made are indeed

the records of events they purport to be (one meaning of objectivity).

Epistemology and Locating Misconceptions

Using the Vee diagrams, students can begin to conceive the structure of knowledge (structure elements and their relations to each other). Misconceptions can be located at the connections between epistemic elements. It is a faulty relation between pieces of the structure of knowledge that permits misconceptions to persist so strongly. The remedy then is to help both teachers and students to reconstruct prior knowledge. The Vee diagram analysis technic helps learners to move between elements--up and down, across, and between elements. This process of reconstruction of claims to knowledge is a primary learning process.

From Epistemology to Learning

Knowing that results in knowledge is a special kind of learning. Knowing and learning are related, but they are not the same thing. I present here one attempt to show relations of the epistemological Vee to the learning Vee.⁷

The Learning V

The main activity of learning as an eventful process is that of reorganization. The active reorganization of grasped meaning involves us in a large number of different actions of integrating and differentiating. Let us place this activity on the learning V (cf. Figure 4).

The learning V shows us a way to use what we know about epistemological elements to think about what often are taken to be psychological elements. Caveats are necessary. Whatever the relation between the epistemological and the psychological is, it is not a reduction—that is, we are not reducing knowing to learning. At the same time we recognize that knowledge is constructed by people, it should not surprise us to find a relation between knowing and learning. Furthermore, and perhaps most important philosophically, knowledge is not the sum total of experience. Most twentieth-century philosophers, in contrast to classical philosophers, accept the point that knowledge is only a part (and a small part) of human experience. Perhaps the rise of scientific knowledge has helped philosophers accept the difference between knowledge and experience. There is much more in experience than knowledge, and knowing that results in knowledge captures only a small part of even known experience. Knowledge is always limited, partial, incomplete. . . .

..... A final warning calls to mind the miseducative workings of indoctrination, conditioning, socialization, and the like. What is learned under these miseducative conditions is not what I mean by learning.

Learning here is nested in the context of educating. Examine Figure 4. Note that the main arms of the V are related by the activities of questioning and the activities of answering. Questioning, like most of the verbs on the conceptual side of the V, works to separate things. Questioning is initially disorganizing; it unsettles fixed and stable claims. Perhaps we have here a reason why much of schooling practice has no genuine questioning in it.



Figure 4. The learning V.

(Recently a teacher was overheard to announce: "When I want your questions, I'll give them to you.") Questioning, imagining, speculating, criticizing, philosophizing, thinking are all ways of separating things so recombining can occur. These actions pull things apart so they can be put back together in a different and more satisfactory and satisfying way. Answering, as indicated by the verbs on the right side of the V, works to organize claims in a definite and stable way. Much of school practice consists of giving definite, almost concrete answers. Perhaps boredom sets in as answers are given to questions that were never asked. The activities of recording, transforming, and claiming are ways of establishing answers. When the connection is made between a good question and its appropriate answer, we believe learning is possible.

Another PhD dissertation study,⁸ done by 'Laine Gurley (Dilger), makes the vital connection between active learning and responsibility. In a year long high school biology course, students instructed in use of Vee diagrams were found to be "on task" in labs upwards of 90-95% of the time, compared to 40-45% of "on task" behavior of non-Vee instructed pupils. Follow-up interviews showed evidence that Vee-instructed students felt more responsible toward their own learning than they had felt before; the Vee empowered them to take charge of their learning. Many more of these school uses are reported in Learning How To Learn.⁹ Principles of Educating: "Go Educating!!"

In the same spirit of Bruner's conceptual commitment to "Go Meta," I advise: "Go Educating!" Much evidence exists of the validity of claims put forth in Educating. Not all of the claims have been tested, so more work is needed. But some claims have multiple sources of support.

Concept maps and Vee diagram analysis can be taught and learned from first grade on to professors with tenure. It is enormously gratifying to me to see senior professors, such as Feldsine and Walter Wesley "come alive" again when they get afresh the idea of making educative events happen. These people change their minds and their work changes. Here is energy for educative reform. Further we continue to get evidence of the creative intellectual power of children.¹⁰ Disaster develops somewhere between ninth grade and college seniors.

In all of our studies where we have asked the question we find much evidence of the educative value of relating, in a deliberate and explicit way, thinking, feeling and acting. We can get at thinking through concept maps. Feeling we can get at through interview, and through video-stimulated recall tapes,¹¹ and through written materials students give us about these matters. Then I see the release of energy aroused, channelled, focused, and relished. It is a good thing for human beings to work at the integration of thinking, feeling

and acting. Acting is behavior governed by meaning. When teachers and students understand meaning, and changing the meaning of human experience, then their acting is informed. They take charge and they learn to trust their own experiencing.

Governance

The ethos of classroom, lab, studio, field work, etc., should be toward shared meaning, toward mutual accommodation, toward that secure cooperation that achieves shared purposes. When this ethos is working, then the need for external governance diminishes markedly. For example, a whole change in the quality of educative human experience comes about when we change our mind about teachers causing learning. Teachers cause teaching; and learners cause learning. Teachers do not cause learning. Learners must first choose to learn. That choice comes before any resolute "deterministic" effects. Here is another place where educational epistemology reconstructs the meaning of old philosophic issues of choice and determinism.

And I might add I see a failure in recent works on the ethics of teaching and administration that attempt simply to apply philosophic treatments of ethics to educational events. The failure comes from the starting point. We should start with educative events, and then see which is and is not the ethics in these events. Utilitarianism and Deontological positions in ethics as treated by professional philosophers cannot be just applied (like a coat of paint) to education. We have to work it through case by case. Kohlberg's work is the classic case of failure.

Empowering Teachers and Students

Educative Episodes: Plateau One.

What did I do to empower John and Karoline? What do I mean by "empowerment"?

I realize now that slowly the term "empowerment" is coming into more frequent use. As its use spreads so

ambiguity will develop because language is creative and meaning changes ubiquitously.

- (a) I believe my first concern is to help students and teachers to trust their own experience. I try to validate their own prior knowledge. I try to get them to "put something on the table" so we can begin to negotiate and share meaning.
- (b) Next, I give them something to do. Right away. They make concept maps of something in their experience that they know very well. Their prior knowledge gets expressed through concept maps. Gowin's Vee is like a large concept map of epistemology. They begin to learn new ideas through using them heuristically in their own fields. Having something new to do underlines the importance of making events happen. The concept map technic not only is something new to do, it validates the students' knowledge and gives them a new power over their own minds. Sometimes this experience is marked by feeling frustrated and agonizing over inadequacies. But it always helps to put the shoe on the other foot--to help them realize they have power over their own learning--indeed, no one else can learn for them. The teachers do not cause their learning. This insight usually releases energy and results in great diversity of student responses. Gradually we all begin to realize we each organize our conceptual images differently. Perhaps we realize it is because of our past that we each and all have largely idiosyncratic experiences. Learning and knowing that are truly ours are different from other persons, but these differences can readily be shared through language and educating. Such diversity is to be prized. Experience can be shared, and that makes educating possible.
- (c) Learning about learning takes time. All learning takes time. And the time it takes is different for all learners. Time is a tyranny in most organized schooling

practices. Usually time is used to control effort directly rather than to control meaning that controls efforts. (Cf. Educating, Chapter 6, "Governance.")

By making these claims I begin to share with my students a subtle insight that perhaps they can control the schooling system by controlling how they spend their own precious time.

Plateau One just described above is usually reached by about the first third of whatever time I have.

(2) Plateau Two requires students to become competent in Vee Diagram analysis. They analyze other people's works. I usually ask them to go after the major authorities in their field. They analyze research papers, books, textbooks, position papers, state-of-the-art declarations, philosophies of the discipline. Empowerment results when they come to understand how fallible and limited expert authority is. Experts disagree. Each teacher must construct their own curriculum and become their own authority. One among many, but still one.

(3) Plateau three begins when students initiate their own research. As they complete this research, they realize their own self-educating. My job is done when theirs is under their own power. What I am able to achieve with my students, I expect them to see they can also achieve with their students. Teacher-student interviews, audio and video taping are highly recommended techniques, something to do that makes records of new events. These records can be studied together by teachers and students. And gradually an educational Vee, a structure of knowledge about educative events, is constructed. As events change in the future, these Vees will also change! Educative events are eventful.

Part III. Concluding Comments.

A worried professional asked me recently, in a despairing tone, "But, where do you bite the elephant?" Isn't the problem just too big, aren't required changes too many? The

resources too few? The thought of schooling as a lumbering, intelligent elephant being bitten hard enough by a Philosophical Gadfly to change direction seems ludicrous at first. My response, however, shows the optimist: make changes where you know something. Reform knowledge is local. Reform can occur in each of the four commonplaces.

Teaching.

- (1) Change our minds. Change from Conventional to Constructivist.

Change our concepts. Go Meta!

Change from reductive simplicities to the set of simplifying assumptions of TLC+G..

Learning.

- (2) Teach students to learn about learning. Promote Thinking, Feeling and Acting: Don't leave out feelings!

Curriculum.

- (3) Change the Curriculum. Use structure of knowledge, Educational Epistemology, Vee diagram analysis. Construct textbooks and syllabi and lab manuals so these show levels of intellectual space, so they become more conceptually coherent and assessable to students. Don't leave out Value claims.

Governance.

- (4) Change system to serve people. Show how organizations can learn.

Mark Twain (of Elmira, New York fame) wrote "nothing so much needs reforming as other people's attitudes." Perhaps our own attitudes can change as well. I know mine have over the years. My optimism is tolerable when I remember the 80%/20% split. I believe it is reasonable to claim that education reform is realizable when powered by a comprehensive, albeit complex, constructivist point of view.

1. John Feldsine, The Construction of Concept Maps Facilitates Learning General College Chemistry: A Case Study. PhD dissertation, Cornell University, 1987.
2. Karoline Fuata'i, Use of Vee Maps and Concept Maps in the Learning of Form Five Mathematics in Samoa College, Western Samoa. M.A. Thesis, Cornell University, 1985.
3. Proceedings of Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, 1987.
4. David K. Cohen, "Teaching Practice." Paper presented at the inaugural conference, University of Chicago, Benton Center, May, 1987.
5. D. Bob Gowin, Educating (Ithaca, NY: Cornell University Press, PB, 1987).
6. Bernardo Buchweitz, An Epistemological Analysis of Curriculum and an Assessment of Concept Learning in Physics Laboratory. PhD dissertation, Cornell University, 1981.
7. Gowin, op. cit., pp. 126-127.
8. 'Laine Gurley (Dilger), Use of Gowin's Vee and Concept Mapping Strategies To Teach Students Responsibility for Learning in High School Biological Sciences. PhD dissertation, Cornell University, 1982.
9. J. D. Novak/D. Bob Gowin, Learning How To Learn (New York: Cambridge University Press, 1984).
10. Marino C. Alvarez, "Using Vee Diagrams To Clarify Third Grade Students' Misconceptions During a Science Experiment" in these Proceedings. Also, Alvarez and Risko (Vicky), "Vee Diagrams: Helping Students Understand the Structure of Knowledge" and "Concept Maps and Vee Diagrams: A Visual Representation of First Grade Children's Thinking." Both papers presented at the American Educational Research Association meeting, April, 1987.
11. Martha Taylor (Robertson), Use of Videotape-Stimulated Recall Interviews To Study the Thoughts and Feelings of Students in an Introductory Biology Laboratory Course. PhD dissertation, Cornell University, 1984.

A View From Britain

W.E. Hartfree

The misconceptions in science and mathematics are many and varied, and any paper about these can do little more than scratch the surface, so those mentioned hereunder can be but only a sample of the more common ones.

Firstly, we need to differentiate between the misconceptions of adults and children, although some misconceptions do exist among both groups. An example of this is a term like transistor. To both adult and child alike, a transistor can be anything from a complete radio or record reproducer, to a mysterious device used in electronics or even a complete chip. Adults have the misconception that transistors wear out - and use the term, often related to the device - 'the transistor has gone'. This is, of course, entirely false - provided they are operated within their designed limits, transistors will last for ever, and it is only when they are overrun that the resulting heat destroys them, the most frequent cause of failure being due to a capacitor failing elsewhere. Adults also think that transistors are delicate, whereas they are extremely robust. Since transistors are relatively new to society - they were not discovered until 1948 - these are misconceptions that cannot have existed before that time. Where then does the misconception originate? Radio and electronic equipment was designed around the thermionic valve, or what Americans call more accurately the vacuum tube. Why did early radio and electronic engineers call them valves? Fleming's valve was invented in 1904, and the device allowed current to flow in one direction only, and eventually, when the third electrode was added, the current flow could be controlled. It is hardly surprising then that the term valve came into use - since this is exactly what valves do - they control flow. The fact that the device would only operate in a hard vacuum was completely ignored, so obviously a sound case can be made out for calling them vacuum tubes, but is this as sound as it appears? The term vacuum tube does not tell us what the device does. Now valves and vacuum tubes are delicate, since the method of operation is to have a red hot wire filament in a vacuum. This necessitated surrounding the device by a glass envelope, - later metal - easily broken. When the transistor made its first appearance - they were equated with valves - after all, to the layman they did the same thing, physicists and electronic engineers will know that there was little in common between early transistors and vacuum tubes. Valves burn out because the filament breaks, - they wear out because the electron emitting substance - the strontium oxide layer on the filament becomes completely vapourised or hardens so that its surface does not emit electrons. The common term used was 'the valve has gone'. Is it so surprising then that this was carried on into the transistor age? These terms or sayings had been in common use for 25 years or more, and had become part of the language.

Scientists search for the truth, and technologists use science to solve problems, but in the past, once having solved the problem or discovered the truth, little was done to disseminate the discoveries outside their own circle. Scientists and technologists are renowned poor communicators. In Britain, one has only to visit the local doctor and walk away with his prescription to the pharmacist, or as the Americans say - the drug store, for the proof of this.

It is a wonder that many catastrophic errors are not made, since most prescriptions have the appearance of being illegible. Does the pharmacist guess what is required by calling on his immense knowledge of pharmacy or not? What is not known is how often the pharmacist contacts the doctor. Does he do this when he tells the recipient to call back in say half an hour, when perhaps he should say, 'I cannot read this'?

In Engineering & Technology is this lack of communication deliberate, and is it a 'carry over' from the Victorian engineers? Brunel certainly expressed the opinion that he was the engineer, and that he did not want his drivers on the G.W.R. to be knowledgeable of engineering, least they thought that they could make a better job of adjusting his locomotives than he could. This certainly percolated down through the Victorian and Edwardian periods among the railway engineers since Dugald Drummond expressed exactly the same sentiments in 1912, and Richard Maunsell reiterated the same sentiments to some locomotive drivers as late as 1935. A century of this doctrine must have become ingrained in our society. The problem is, how do we overcome it? Do we have a parallel case with the Nuclear Power Industry? Atomic power stations have been operating in Britain since 1956. Little effort was made to educate the masses on the advantages of the generation of electricity using nuclear fuels. It does appear once again that the masses are being misinformed, and little is being done to redress the balance. In fact, it took a near disaster at Chernobyl in the Soviet Union for anything to be done at all, and it is only since that time that any real effort has been made to correct the false concepts of the dangers of the nuclear power industry. All too often cases are presented as negative ones rather than positive ones, and little is done about it. The 6 mile island incident was displayed very prominently in Britain as an example of why we should not build high pressure water reactors, and when it was put to the anti nuclear lobby that no accident actually occurred, they quite glibly said 'but think of what could have happened'. As far as I am aware, the counter argument, that there was sufficient control to avert a disaster, and this control was put into effect, was never put - certainly not on the British side of the Atlantic, and this is where the people who are knowledgeable are doing the whole community a great disservice.

This perhaps begs the question - Do engineers and Technologists actually encourage this lack of communication - i.e. is it deliberate? As a result we do have a real problem, worldwide. The disadvantages of the generation of electricity by using nuclear fuels, are the subject of world wide protestations by particular pressure groups - often referred to as the anti nuclear lobby. These groups are often mistakenly referred to as the nuclear disarmers. It is not the nuclear disarmers to which I refer, but the anti nuclear campaign - i.e. no nuclear energy. As far as I am aware, there are no organisations existing which say we should build nuclear power stations to prevent the discharge of large volumes of sulphur dioxide into the atmosphere to prevent acidic rain. They do protest about acidic rain and the destruction of trees in Norway, but they do not suggest that the coal fired burning power stations should be replaced by nuclear power stations. The scientists and technologists have once again failed to put the positive aspects to the nonulus. It does appear that the masses are once again being misinformed, and little is being done to redress the imbalance.

The disposal of nuclear waste is topical and gives concern for the safety of people living near nuclear power stations, but it is doubtful that many of their fears are justified. There is some inevitable risk in any operation, whether it be medical or otherwise, but what has to be carefully considered is the advantages gained against the disadvantages. Is the risk worth taking or is it not - just how big is the risk, and is it acceptable? Again engineers and technologists are aware of the risks - but do they give them enough publicity, and do they put them over in a fair and proper manner? To me it seems extremely unlikely that they do - and it would appear that the view is taken that it might be better if they were hidden, i.e. 'we will say nothing about this'. Ignorance is the order of the day - it is the safety valve - keep the masses ignorant and you will be safe - until that is that somebody finds out. By then you hope it will be too late to do anything about it because the misconceptions will be well rooted and very difficult to eradicate.

Misconceptions in Mathematics may be easier to erase than scientific or technological misconceptions. Much of technology is a matter of opinion, and it is this which makes it technology. Many attempts have been made to define technology - some more successfully than others - but where does the boundary between science and technology occur? I would suggest that the difference between applied science and technology is that in applied science all the answers can be calculated, but in technology there has to be some degree of intuition. As soon as somebody says - 'that ought to do it', or 'that is about right' then it becomes technology. Sometimes the engineers and technologists get things wrong. If they did not, then disasters like the destruction of the suspension bridge over the Tacoma narrows, and the Milford Haven and Hobart box bridge disasters would never have occurred. Currently, the whole design concept of roll on - roll off ferries is in question after the Zeebrugge disaster. Were the risks known and accepted? The accident rate for cross channel ferries is very low - was it that the risk was unknown and only came to light after an accident had happened and even then only found after an intensive investigation and a public enquiry?

In Mathematics children are taught for many years that answers are either correct or incorrect - in short they are marked with a tick or a cross. It is not surprising that this conditioning stays with them. Although the so called Modern Mathematics (S.M.P. etc) has gone some way towards eradicating this, this system of things being right or wrong is still deeply entrenched in our children. It does seem that insufficient work on estimation and the limitations of estimation is the norm in most school subject areas. Even in Mathematics, pupils are rarely sufficiently encouraged to obtain an accurate estimate first - indeed many pupils are unable to do so since many teaching strategies prevent this. In many Mathematics courses work on the order of magnitude is often conspicuous by its absence. This is very surprising since most of the calculations that the pupils will have to make during their adult working life is one of estimation. Many confuse estimation with the wild guess. The wild guess is usually based on no information whatever, whereas the process of estimation is one of gathering as much information as possible, and then to reject the absurdities, and then to narrow the estimate to the smallest possible limits. The pupils also need to understand just how accurate an estimate can be for it is as absurd to make an over accurate estimate as it is to make a wild guess. Again this is a problem of the order of magnitude.

One of the things that becomes apparent is the difficulty of teaching estimation and the order of magnitude, but this does not mean that we should fight shy of it. The modern world has become a computer orientated society - indeed the present trend appears to be one where a computer is purchased and we look for jobs it can perform. The practice should, of course, be the other way around. If we have some task to undertake, then consider if a computer can do it more accurately and more efficiently. However, the main concern is to ensure that the computer gives the right answer. Some would argue that the computer cannot possibly give the wrong answer, since it gives an accurate answer, given the information with which it is supplied. How do we know that the correct information has been fed into the computer? i.e. the programme is correct. We need to know the order of magnitude of the answer, because if the wrong answer is being supplied, the computer's answer will be so far off that the estimate will indicate very clearly that something is amiss.

Some misunderstandings are due to either weak or unclear nomenclature or the misunderstanding thereof. For example, the one misunderstood most by lower school pupils is that $a^2 + b^2$ is not $(a + b)^2$. Is this due to faulty or weak teaching strategy, in that insufficient emphasis is placed on the proof? Other common mathematical misconceptions include:-

- (a) that indices have to be whole numbers.
- (b) indices only operate to the base 10, (although S.M.P. and computer studies have gone a long way to eradicating this one)
- (c) that the laws of indices do not work in all cases.
- (d) negative indices do not exist.
- (e) $10^{-2} = \sqrt{10}$ etc.

Design studies, craft studies and technology studies are not immune either. There is still a strongly entrenched school of thought that says 'the thicker and heavier it is, the stronger it will be'. This is a false concept handed down from the engineers of the Victorian era. An object is not strengthened merely because the amount of material used is greater. Often an increase in size and weight of a particular member of a structure will weaken the total structure. Certainly the particular member itself will be strengthened, but this increase may well move the combined stress to some other area which will result in weakening the whole structure and therefore lessen the load that the whole structure can take. The converse is also true. Whilst loads can be taken by the structure as a whole, if one particular member is removed then the whole structure can collapse as accumulative loads build up. An example of this was the collapse of the block of flats at Ronan Point in London. A gas explosion blew away part of an inside wall, and as a result the whole corner of the block of flats slid down to ground level. This collapse was caused by the pressure formed by the weight of the upper stories on the fifth floor, the one with the missing sections. Although this tower block had been designed to withstand wind pressures on the walls of up to 120 knots, nobody had thought about what would happen if one of the interior walls was removed. Pressure from above had not even been considered.

In Physics and Chemistry, the confusion between weight and mass is no nearer solution. This misconception continues to exist at all levels - student and adult alike. The space programme has been instrumental in making a start to solve this problem, but educationalists have so far failed to capitalise on this fully. Because the media is able to show visually that astronauts in space are weightless, and there is plenty of talk about escaping from the earth's gravity, there is some improvement in the lay persons understanding of weight and gravity, but mass is a term that is seldom used, and is one that is certainly not understood. There is another misunderstanding that is troublesome and that is the belief that only the earth has gravity. As space travel becomes more the norm in say the year 2050, then the difficulties of understanding weight, gravity and mass are likely to increase for the average pupil, but for the 'A' level student of Physics, these concepts are likely to be more easily understood since the syllabus content now includes work on satellites etc. In many schools there is already a division between the Science/Technology students and the rest, and I am told that this is particularly apparent in the U.S.A. where the problem is sufficiently entrenched that the result is that seminars such as this one are being called in order that the problems can be discussed. The U.S.A. is not alone in this. A new cult has come to the forefront in Britain - what is known as 'The I Know No Science Society'. Even some teachers are quite proud to boast that "nobody is more ignorant of science than I am" - a very proud boast, as if this is some magnificent achievement. Is it small wonder then, that this is passed on to the pupils. I often wonder what their reaction would be if they were to be answered in some obscure foreign language and then the declaration was made that there was a total lack of understanding of the English language, or even better to respond with some mystical sign language and then to declare that there was a total ignorance of any spoken word. Would they consider that this was a total failure or a colossal achievement?

In Chemistry the distinction between atoms and molecules continues to give difficulty at all levels. The term atom is frequently used although it is often misunderstood. The lay persons idea of an atom is generally that these dangerous atoms exist - that they have only recently been discovered by the Scientists and that they cause devastating explosions. These false concepts are linked to the nuclear power industry, and to the nuclear weapons industries, and reference has been made to this earlier. Perhaps this may give the necessary impetus for those who seek to promote a more technologically literate society - but something more is needed than just to be able to read the words and know what they mean. Little will be achieved unless there is understanding to go along with the literacy. Perhaps a start should be made by teaching that the generation of electricity by nuclear power is all about control - control of the atom - control of the amount of energy atoms can produce - control of the supply of electricity i.e. the supply being matched to the demand.

The home computer industry is a rapidly developing one. Britain has more home computers per head of population than any other country in the world. How has this affected misconceptions in Science and Mathematics? The "so called" generation gap is getting wider - has the home computer encouraged this, or has it

helped to overcome it? I would suggest that the first is the case. Professor T. Stonier maintains that we are further into the computer age than we think. He suggests that we are about halfway through the computer age. There is little doubt, however, that our young people have grown up with computers, and many young pupils use computers as toys. 4 years ago at Christmas, the greatest sales from the toy shops of Britain was computers. A new lucrative industry was created in computer games software. The introduction of the Schools Mathematics Project - (Modern Maths) into the schools greatly encouraged the use of computers by young pupils, and the parents, brought up on the old mathematics syllabuses, were not only completely 'befuddled' but often lacked the ability to comprehend what was happening. As a result, the generation gap has vastly increased, and all too often teachers hear the comment from parents "We did not do that when we were at school". This can lead to hostility in the family between parent and child, since the parent has a feeling of inadequacy, and the child is sure that the parent is inadequate - or that the parent is being obstructionist and unhelpful. In 1985, the computer software industry became alarmed at the pirate copying of video tapes and computer software. Research by the industry showed that by far the vast majority of the pirating was being performed by children under eight years of age, and the British law prevented the industry from prosecuting offenders under 10. It is a certainty that a great many of the parents lacked the ability and the necessary know how, to reproduce the copies as their children had done, and were thus completely unaware of what was happening.

Many various bodies have been set up by the Schools Council, and various projects have been funded by them. "The Concepts in Secondary Mathematics & Science" (C.S.M.S.) finished in 1979. The project, like most others generated a large amount of data, some of which concerned the occurrence of specific errors. The Strategies and Errors in Secondary Mathematics (S.E.S.M.) was funded to investigate the cause of some of these errors. Once again, this is the case of proving what is already known. Teachers know only too well where the weaknesses and the misconceptions are. What is needed is a teaching strategy - well researched and tried - which overcomes these false concepts and errors.

Perhaps one of the difficulties is that we always start at the wrong end. The Nuffield Science Schemes did much to improve science teaching in schools, but when Nuffield was first introduced, there was a great deal of nonsense talked about the Nuffield Schemes. They started at the secondary level and said that Nuffield was only for the top 20% of the ability range. As a teacher you either did the Nuffield Scheme in its entirety or not at all. The schemes were eventually watered down for younger pupils and the lower abilities. Nuffield Primary Science turned out to be a disaster. This led to the writing and introduction of Nuffield Science 5 - 13, - a huge success. The introduction of Technology into the schools has followed a similar road. Introduce it into the 6th forms, and gradually work your way down. I would suggest that this is the wrong route. Why not accept that there are short comings? Introduce what is thought to be correct at the base level - i.e. as low and as young as is possible - then build upon this foundation as the pupils progress through their schooling - until the desired aims and objectives are reached.

This begs the question as to the origins of the curriculum developers. How many of them have taught in Primary Schools and for how long? Certainly most of the ones that immediately come to mind, have their origins in the Secondary Schools. Could it be that the misconceptions and errors become more apparent at the secondary level and that curriculum developers try to correct the faults at the level where they appear, rather than to seek out its root cause, and discover not where it appears, but where the errors became introduced and how they got there in the first place?

The National Foundation for Educational Research has made some attempt to research the errors and misconceptions that are apparent in mathematics at the secondary school level, but in the sciences and technology, the old familiar scene is all too apparent. The line followed is, what is missing from the syllabus content and how do we put it in - and what do we take out in order to fit it in. Little or no work is being done to correct errors or to find methods of teaching that will eliminate the errors. The Engineering Industries Training Board has set up its own research programme into what is wrong with the Mathematics content in various syllabuses. This has been funded by Shell and is based at Nottingham University. The engineering industry has been very forthright in its condemnation of mathematics that is taught in schools and has issued statements of what school leavers ought to know when they enter this industry. Nobody has said exactly how it should be taught, and neither has anybody said anything constructive about how the misconceptions should be removed, or about how they can be prevented in the first place.

Research into misconceptions in mathematics carried out by K. Hart of Chelsea College concluded, "The results of the investigation point to the conclusion that specific intervention at a particular time seems to have been effective with most children as far as the abandonment of the incorrect strategy is concerned, and with many children when the correct responses were required. The difference between the work attempted in S.E.S.M. and the usual class 'correction' was that the reasons why the children were failing were thoroughly investigated and the remediation took into account their naive and child methods besides considering the transition to more formal (and generalisable) methods. In nearly all the classes investigated, it was apparent that certain errors were more resistant to change than others. Some children did not improve their performance even though using the materials, but the approach would seem worthwhile". Note that there is no mention of how the errors got there in the first place.

What strategy or strategies should be applied to prevent misconceptions and errors? The first problem is to identify what the errors are. This should not be difficult or expensive. A questionnaire to a number of teachers should be sufficient to provide a large enough selection of errors. The next step is one for the researchers and would be costly. Where do the errors come from, and how have they been formed? Having achieved this - if it is possible, then we may be able to provide teaching methods and programmes that will prevent the misconceptions from becoming established. Perhaps we have forgotten what Cattell said many years ago - "Give me the child until he is 7 and you can then do what you like with him".

THE USE OF CONCEPT MAPPING TO DIAGNOSE MISCONCEPTIONS IN BIOLOGY AND EARTH SCIENCES

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THE NATURE OF MISCONCEPTIONS

The notion of "misconception" bears a negative connotation that reflects value judgement. Therefore we start with the notion of "conceptual framework" which is a system of concepts and the propositions that relate them to each other (thus forming ideas of larger scope), and procedures designed to account for a knowledge domain with its parts and aspects or performance on problem solving and other reasoning tasks within this domain. Concepts assume their meaning from their relationships with other concepts within a conceptual framework and their position in the total configuration of concepts. As pointed out by several authors (e.g., West and Pines, 1986) there may exist two types of conceptual framework, namely, personal, or real life, and "official" or "scientific", the relationship between which may vary. A conceptual framework is considered inadequate if it does not properly account for the phenomena it is designed to explain, and incorrect if it is incompatible with the official one(s). By "misconception" we refer to part (either concept or idea) of a conceptual framework that

mismatches official ideas. This definition is equivalent to Strike's (1983), since according to schema theories it implies that making use of such part for functioning within that domain must necessarily result in mistakes. One way to identify misconceptions is to tap a particular conceptual framework and detect inconsistencies between its parts and an official one, and we propose that concept mapping is a highly appropriate means to this end.

In this paper we want to make the point that the knowledge structure characteristics obtained by our analysis scheme of cognitive maps can serve to tap misconceptions that result from deficient learning. Preliminary work in this direction was started by Feldsine (1983), and we report the results of two studies. The first study deals with the development of biological knowledge structures of prospective teachers. They participated in the methods course that dealt with theoretical and practical pedagogical principles, had been exposed to field experience and had taught several biology classes. The second study deals with the knowledge acquired by students who enrolled in an introductory earth sciences course which was preceded by an introductory course in geology. Hoz, Bowman, and Kozminsky (1987) evaluated this course using concept mapping. In these studies the students were interviewed by ConSAT (Concept Structuring Analysis Technique, Champagne and Klopfer, 1981). Their cognitive maps were analysed according to various cognitive structure dimensions that were developed by our research team and described by Hoz (1987).

Concept mapping was first proposed by Joseph Novak in the 70's and several versions were developed since then. In our study we use the revised and standardized form (Hoz et al., 1984) of ConSAT. The use of ConSAT involves three steps: determination of the list of concepts, administration of the ConSAT interview, and analysis of the obtained cognitive maps. The chosen concepts can be of the same or different generality or abstractness, depending on the researcher's objectives and their optimal number ranges from 10 to 15. This version of ConSAT makes it possible for the interviewee to form groups within his or her cognitive maps and our analysis scheme is based on both their existence and nature.

The ConSAT interview involves six phases:

1. A short training session with six daily concepts for demonstrating to the interviewee the procedure and the kind of products expected (i.e., a cognitive map that includes all the possible meaningful links and their labels).
2. Classification of each list concept as familiar or unfamiliar.
3. Giving a verbal definition or explanation for each familiar concept. The definition are written down by the interviewer.
4. The construction of a map of the familiar concepts by spatially arranging their cards on the table so to reflect their organization and mutual relationships. When the interviewee is satisfied with his or her arrangement it is being written down by the interviewer on a large sheet of paper. The interviewee is further asked to state what concepts are related and express verbally the most meaningful relations he or she knows among them

and between groups of concepts (if such were formed). These propositions are written by the interviewer on the lines connecting the concepts. The interviewee is also asked to provide a title characterizing the whole map and to explain the nature of groups. The interviewee is allowed to modify the arrangement during the interview until it satisfies him or her.

5. The interviewee reinspects the unfamiliar concepts and is asked to add the concepts that were recognized now as familiar to the map, along with appropriate labels. Also, he or she is allowed to add relevant concepts that were not on the list.
6. The interviewee is asked to indicate the link strength between all pairs of list concepts, regardless whether or not they were linked in the cognitive map. The three level strength scale includes necessary links between concepts that are tightly connected and interact strongly (level 2), possible links between concepts that are moderately connected and interact slightly (level 1), and links that are disciplinarily meaningless or illegitimate, and its existence is forbidden (level 0). The strength levels for all bi-concept links were recorded in the individual link strength matrix and a similar official link strength matrix is constructed by the experts.

Thus ConSAT yields three kinds of products: (i) concept definitions, (ii) a cognitive map that is a network representation of the concepts and their mutual relationships, and (iii) characterization of concept groups, if they were formed, and of the organization of the whole map. Sample cognitive maps are presented in the next sections.

An analysis scheme was developed that pertains to four components of cognitive maps--links between concepts, meaning of single concepts, concept groups, and the organization of the whole map--and to link strength matrices (concept definitions are treated separately). The analysis of cognitive maps is done in two levels. The first involves visual inspection of certain surface features, thus rendering the cognitive map a low inference measure that minimizes possible inferential leaps in the abstraction of knowledge structure characteristics. The second level of analysis deals with substantive deep structure characteristics underlying the structure and nature of the cognitive map components.

To identify and tap misconceptions in each discipline agreement was reached between several experts that yielded four types of "official" or "legitimate" measures: (i) all possible bi- or multi-concept connections and valid statements that express them, (ii) forbidden bi-concept links, (iii) partition or partitions of the concepts into groups, and (iv) overall conception or conceptions of the domain spanned by the set of concepts.

A. Links in cognitive maps are classified into three categories:

links among individual concepts within and between groups, and links between groups, if groups were formed in that cognitive map (otherwise only links among individual concepts are considered).

Official partitions are the partitions that the experts agreed on as disciplinary legitimate. Group homogeneity reflects its tightness, namely, the degree to which (i) the concepts in that group have the same or similar disciplinary meaning or belong to the same category, and (ii) it overlaps an official group. When no groups were formed only the first kind of link applied.

Appropriateness of group characterization is the extent to which the group's title fits its constituent concepts and their underlying common characteristics. A kernel group in cognitive map is one whose majority or all intra-group links (regardless of their validity) are at the interviewee's link strength level 2.

B. Link validity is the disciplinary correctness that is assessed on a four-level ordinal scale: correct, precise and clear; correct but partial; indirect and general, or imprecise and lacking in certain aspects; and incorrect. The median validity reflects the typical validity for individuals or groups. Map's salience involves two types of bi-concept links and reflects the agreement between the interviewee and the experts with regard to the importance they attribute to links. (i) The percentage, out of the total number of links in the cognitive map, of all links in the cognitive map whose expert strength levels are 1 and 2. Its complement is the percentage of forbidden links (ii) The respective percentage of the valid links.

C. Focal concept is one having the largest number of intra- and inter-group links with other concepts (relative to other concepts in the particular cognitive map). Concept meaning can be gleaned from the concepts to which it is connected and the nature of the relationships. The concept's extension is determined by the size, nature and complexity of the small knowledge structure that is attached to it and by its relations with the other parts of its conceptual framework. Therefore, the concepts related to a focal or any other concept can be used to characterize its meaning for

the student.

- D. Overall conception of the domain spanned by the concepts is the interviewee's characterization of the organization and structure of the cognitive map. If groups were formed it refers to their interrelations. This measure is similar to that used by Champagne, Klopfer, DeSena and Squires (1981).

Operational definitions can now be proposed for a variety of misconceptions which are based on several of these features of cognitive maps. Misconceptions refer to any mismatch between the official and student's conception regarding (i) individual concepts, as evidenced from their relationships with other concepts and the group into which they were classified, and (ii) to ideas, as evidenced from the nature of their representation by concept groups and the principles that underlie the organization of the whole set of concepts.

This definition enables the detection of misconceptions that cannot be derived from analysis of concept definitions. Concept definition contains certain specific agreed upon concepts whose relationships with the defined concept span this concept's meaning. However, concept definition can be of very limited help in finding out the concept's meaning. Correct concept definitions can be interpreted as everything from complete mastery of the concept to the perfect ability to remember verbal statements rotely. Incorrect concept definition can be interpreted as everything from evidence of imperfect ability to remember verbal statements to total confusion. Furthermore, even if total confusion is the case, an incorrect

definition does not explicate a specific misconception but only indicate incorrect understanding. The proposed dimensions of cognitive maps can serve us better in tapping misconceptions by providing wider and richer perspective than definitions on (i) the concept's relationships with many more concepts in and outside a group of concepts in which it might have been grouped, and (ii) on larger assemblies of concepts that comprise more comprehensive ideas.

We use these features of cognitive maps to detect misconceptions in the following ways.

- A. Failure to form an official group, dispersing its constituents between other groups, or grouping concepts on the basis of surface structure (or verbal) rather than deep structure features. The formation of inappropriate groups can indicate misconceptions regarding essential important common deep structure features of certain concepts and the ability to conceive of a group of concepts of higher abstraction level. Examples are (i) the formation of small groups that are not merged into a more comprehensive group, (ii) the formation of several two-concept groups with a certain relation between their components, instead of grouping the respective concepts in each relation into two more general groups, (iii) the inclusion of a concept in the group containing its examples rather than in a group of general concepts, and (iv) classifying general concepts with their instances rather than with concepts of higher abstraction. Giving a group label that is too general, vague, or invalid can indicate misconceptions regarding the differentiation of the groups' concepts. The existence of isolated concepts that are neither included in any group nor connected to other concepts can indicate

misconceptions regarding general categories that may either not exist in the student cognitive structure or is distorted.

B. Formation of invalid connections within or between groups or making forbidden links between concepts. Formation of official or other disciplinary legitimate groups without making the necessary intra-group connections between their component concepts, and failure to form necessary substantive within- or between-group connections.

C. When no groups were formed, arrangement of the whole set of concepts on the basis of their proximity in time and space, their position in the instructional sequence, or other irrelevant features rather than on substantive grounds. These can indicate misconceptions regarding the principles underlying the domain and the ability to distinguish didactic from disciplinary considerations.

The use of these indicants to tap misconceptions is demonstrated in the domains of biology and earth sciences.

MISCONCEPTIONS IN BIOLOGY

We present misconceptions pertaining to three concepts by analyzing their links with other concepts: diffusion, metabolism, and energy. Diffusion and metabolism are broad and general processes and can therefore be considered part of several conceptual frameworks. All

biological processes are contingent on the use and transformations of energy, a principle that underlies parts of almost every biological conceptual framework.

We describe several links among concepts within cognitive maps, show what misconceptions are indicated by them, and point to possible sources for these misconceptions.

We present ten invalid relationships between diffusion and other concepts: Influx and eflux of materials to and from the cell is achieved by diffusion and are in opposite direction to the diffusion gradient. Diffusion enables entrance and exit of materials to and from the cell. Large amounts of material are absorbed and released by the cell and this is dependent upon diffusion. There is diffusion of substances in and out of the cell that enable cell growth. Metabolic substances enter and exit by diffusion. The connection between the cell and its environment can be achieved by diffusion. Diffusion is a process that participates in metabolic activities between the cell and its environment. Diffusion is a process in which metabolism is achieved through the cell to the environment and it is accompanied by energy consumption. There is transition of substances between adjacent cells through the cell membrane and this transition is operated by diffusion. The cytoplasm obtains or releases different materials by diffusion according to the cell's needs.

These relationships indicate a misconception regarding diffusion, relating it to the processes of entrance to or exit of substances from the cell through its membrane that neglect two essential features: (i) substantial portion of the matter transference through the cell membrane is achieved also by other processes different from diffusion, and (ii) transference through semi-permeable membrane does

not occur by diffusion but rather by osmosis, which is a special case of diffusion and differs from it in certain characteristics.

These misconceptions may have been produced by inappropriate presentation of diffusion in the textbooks that were available to the students. Most of the examples given to diffusion are actually osmotic processes, with no reference being made to the distinction between these two. For instance, to illustrate diffusion the example describes how water molecules enter the cell through its membrane, namely, osmosis (Galston, 1968).

We present ten links of etabolism with other concepts, of which the first three relate to metabolism and diffusion, the next two describe the relations of metabolism with other concepts and the last five view metabolism as an auxiliary process by which biochemical processes are carried out: For photosynthesis to occur there must be metabolism during diffusion. Diffusion is one of the ways for metabolism. Diffusion can be obtained by metabolism. To survive the cell needs metabolism to occur between it and the environment. Breathing produces by-products of which we get rid by metabolism. Breathing takes place with the aid of metabolism. Photosynthesis takes place with the aid of metabolism. Energy is produced from metabolism and photosynthesis. Fat dissolution is achieved by metabolism with the aid of enzymes, and ATP is formed. Metabolism is the basis for breathing processes. The are interrelated.

Misconceptions of metabolism emphasize the transference of matter between the cell and its environment, namely, the entrance of certain matters to the cell and exit of different matters from it. However, metabolic processes occur both within and out of the cell. This misconception disregards some of its essential subprocesses and

therefore comprises only a small part of the extension of this very general notion. These misconceptions may arise from (i) the inability to identify the metabolic nature of certain processes, (ii) the inability to integrate and differentiate simultaneously all aspects of certain processes, or (iii) the Hebrew term for this concept, which is "exchange of materials".

Energy is related to other concepts, such as respiration, photosynthesis, metabolism, ATP, and fats degradation. These relationships are illustrated by the 15 following links: There are respiratory enzymes which produce energy. Respiration produces energy. Fat degradation takes place in order to produce energy too. Enzymatic processes utilize or release energy. In the process of respiration energy is invested. Processes of metabolism which take place inside the cell utilize energy. Energy is needed in respiration and photosynthesis. Metabolism, mitosis and respiration are processes which require energy. Respiration is a way by which the cell utilizes energy through respiratory enzymes. The process of carbohydrate storage requires energy. Photosynthesis is a way of energy supply and glucose storage. Energy is produced inside the cell. Energy is the last product of respiration. In photosynthesis the energy of light serves for the initiation of a process in which energy is produced during its different stages. Metabolism is needed in order to produce energy.

These links indicate the major misconception that energy can be produced or dissipated in biological processes, reflecting inability to distinguish energy production and dissipation from energy transformation. (According to the law of the conservation of energy, in closed systems energy undergoes transformations but can be neither

dissipated nor produced.) This misconception may have arisen from the daily and sometimes scientific use of the concept, where statements like "energy disappeared in this process", "this process consumes energy", or "heat energy is produced in this process" are often heard and used.

MISCONCEPTIONS IN EARTH SCIENCES

Two official partitions of the central concepts in the course "introduction to geomorphology" were formed. The first is based on an environmental approach and comprises three groups. Fluvatile environment concepts: lateral erosion, vertical entrenchment, river terraces, flood plain, fluvial system, and base level. Karstic ground water environment concepts: solution, caverns, seepage, and intake area. Slope environment concepts: slide and scar. Three concepts remained isolated: equilibrium, coastal zone, and glacial landscape.

The second partition is based on the distinction between four classes of concepts. Process concepts: solution, seepage, slide, lateral erosion, and vertical entrenchment. Resulting land forms concepts: caverns, scar, flood plain, and river terraces. System approach concepts: maturity, equilibrium, and base level. General environment concepts: fluvial system, coastal zone, and glacial landscape.

The following misconceptions were revealed.

1. Misconceptions regarding basic facts can be identified by the existence of forbidden links or mistaken explanations for links between concepts. Examples are: (i) river terraces are formed by

slides or by solution, (ii) seepage causes entrenchment, (iii) glacial elements indicate a mature stage of desert landscape, and (iv) erosion is typified by caverns.

2. Misconceptions regarding the ideas and principles underlying the official partitions can be identified when all the concepts were arranged in one large single group that contrasts with the official partitions. An example is the cognitive map in Figure 1. The title that expresses the rationale or underlying principle for this big group provides clues as to possible misconceptions regarding single as well as closely located concepts. An example is a large group which is arranged in a flowchart form, emphasizing the fact that water and sediment were moving downwards through the landscape, in the order: "water from the fluvatile system may seep, seepage causes solution, solution forms caverns, and caverns may reach maturity"; This arrangement is based on the spatial proximity between concepts, with each element flowing towards and triggering the next one, and is arranged so to simulate the relative height of elements in the environment, with the base level as the sink, being located at the lowest part of the map. Apparently, by dominating the students' conceptions ideas like "flow patterns" prevented the grouping of concepts.

When partition was achieved, misconceptions can be identified by detecting general ideas whose extension is different from that of the official conception. Examples are the system approach and environment. Misconceiving the general notion of system approach is evidenced by the following findings: (1) Two of its constituent concepts, maturity and equilibrium, were sometimes included in

different groups but typically remained isolated. (2) Another concept, base level, was often identified with the concept coastal zone. This identification was probably based on their physical proximity, ignoring the central function of base level in the fluvial system. (3) The system approach group was never formed. Misconceiving the general notion of environment is detected by not forming a group comprising the general concepts glacial landscape, coastal zone, and fluvial system. The confusion regarding the idea underlying this group is evidenced when coastal zone, ground water, and fluvial system were grouped together.

3. Misconceptions regarding differentiation between concepts can be identified by the existence of "overconnections" and "underconnections". The first term indicates a large number of links produced by connecting every concept with almost every other concept. The second term indicates the formation of very few links within and between groups, often with no link labels. Overconnections (illustrated by the cognitive map in Figure 2) reflect lack of knowledge that certain links should not be made and underconnections (illustrated by the cognitive map in Figure 3) reflect lack of differentiation between concepts.

4. Misconceptions can be identified by incongruity in the nature of the groups in the official partitions and that of students' groups. The nature of groups is determined by their homogeneity and completeness, by the existence of intra-group links, and by the groups' abstractness. Group homogeneity is contingent on the nature of its constituent concepts and the group's label that reflects its

essence. Misconceptions regarding the ideas and principles underlying the official partitions are reflected in low group homogeneity and dispersion of concepts belonging to an official group between different groups. Examples of low homogeneity groups are: (i) maturity (system approach), slide, and solution (processes), (ii) glacial landscape (environment), scar and caverns (land forms), (iii) base level (system approach), caverns (land forms), and vertical entrenchment (process), and (iv) maturity (system approach), scarp (land forms), lateral erosion (processes), and glacial landscape (environment).

Too general, vague and inclusive group labels can indicate misconceptions regarding the substantial common features of certain notions. For instance, the very general and inclusive label "concepts related to water and water processes" is assigned to the group comprising the concepts river terraces (fluvial) and solution (karstic), thus mismatching the essential common features of these concepts.

Misconceptions regarding an idea that characterizes an official group can be indicated by the existence of isolated concepts and incomplete groups. Incomplete group is a homogeneous subgroup of an official group. An instance is the group comprising solution and caverns with the label "solution produces caverns". Isolated concepts reflect difficulties in conceiving of or abstracting the principles underlying environment and the system approach conceptions, or poor knowledge of taught principles. An example of poor knowledge of basic facts is the concept intake area which is isolated from the karstic-related group (solution, caverns, intake area, and seepage). The majority of isolated concepts were either environment-related

(coastal zone and glacial landscape) or related to the system approach (equilibrium and maturity).

Misconceptions regarding the organizational principle of the group and the interactions among its constituents can be indicated by the lack of most of the basic important and necessary intra-group links. Examples are (a) the group of concepts related to the fluvial system (river terraces, vertical entrenchment, flood plain, and lateral erosion): (i) No link existed between river terraces and vertical entrenchment, whereas river terraces are produced by vertical entrenchment, (ii) no link existed between river terraces and flood plain, whereas river terraces originate from flood plains, and (iii) no link existed between vertical erosion and lateral erosion, which are complementary processes within the fluvial system. (b) The group of concepts related to the environment (lateral erosion, slide, and coastal zone): (i) Lateral erosion and slide were not connected, whereas lateral erosion causes slides, and (ii) slide and coastal zone are not connected, whereas the latter is the typical environment where slides often occur.

Misconceptions can also be indicated by the group's abstractness, since the more abstract and varied (coming from different domains) the concepts in a group, the higher its quality. An example is the abstract notion that "processes mold land forms" which predominated some groups (e.g., rivers form a flood plain, and a slide may result in a scarp). However, grouping processes from the different environments was not attempted and students did not produce one group comprising processes (like solution, seepage, vertical erosion, and lateral erosion) and other group comprising land forms (like flood plain, river terraces, and caverns). This misconception reflects the

possible blurring of inter-system relationships by the intra-system relationships.

As in biology, instruction seems to be a source of several misconceptions. The reasons for this hypothesis are as follows:

1. The course content presentation followed the physical movement of material in nature, starting with weathering on the slope, continuing through mass-movement and transportation in channels. It is possible that this instructional sequence was misunderstood as an essential feature in earth sciences.
2. The course was organized around environments, discussing one environment after the other, focussing mainly on their inner functioning, and on the interactions among their elements. This may be the source of the concentration on intra-system functions and relative disregard of the inter-system links.
3. Misconceptions regarding the environmental approach may have resulted from the course highlighting intra-system processes and disregarding the overall environment characteristics.
4. The course demonstrated the system approach by analysing fluvial processes. The abstraction of the notion of system approach was probably hindered by this instructional mode.

- Champagne, A.B. and Klopfer, L.E. (1981). Using the CONSAT: A memo to teachers. Pittsburgh: Learning Research and Development Center, University of Pittsburgh.
- Champagne, A.B., Klopfer, L.E., DeSena, A.T., and Squires, D.A. (1981). Structural representation of students' knowledge before and after science instruction. Journal of Research in Science Teaching, 18, 97-111.
- Feldsine, J.N. (1983). Concept mapping: A method for detection of possible student misconceptions. In H. Helm and J.D. Novak (eds.) Proceedings of the International Seminar on Misconceptions in Science and Mathematics. Ithaca, NY: Cornell University.
- Galston, A.W. (1968). The life of the green plant. (Hebrew translation) Tel-Aviv: Yachdav and Sifriat Poalim.
- Hoz, R. (1987). Dimensions of teachers' knowledge structures and their identification by concept mapping. Paper presented at the AERA annual meeting, Washington DC.
- Hoz, R., Mahler, S., Yeheskel, N., Tomer, Y., and Elbaz, F. (1984). Project for the Evaluation of Teacher Education (PETE) Annual Report. Beer-Sheva: Ben-Gurion University of the Negev.
- Hoz, R., Bowman, D., and Kozminsky, E. (1987). The role of prior knowledge in learning: A study of students' cognitive structure in an earth sciences course. Paper submitted for publication.
- Strike, K.A. (1983). Misconception and conceptual change: Philosophical reflections on the research program. In H. Helm and J.D. Novak (eds.) Proceedings of the International Seminar on Misconceptions in Science and Mathematics. Ithaca, NY: Cornell University.
- West, L.T.H and Pines, L.A. (1986). Conceptual understanding and science learning: An interpretation of research within a sources-of-knowledge framework. Science Education, 70, 583-604.

Figure 1. Cognitive map comprising a single group.

BALANCE

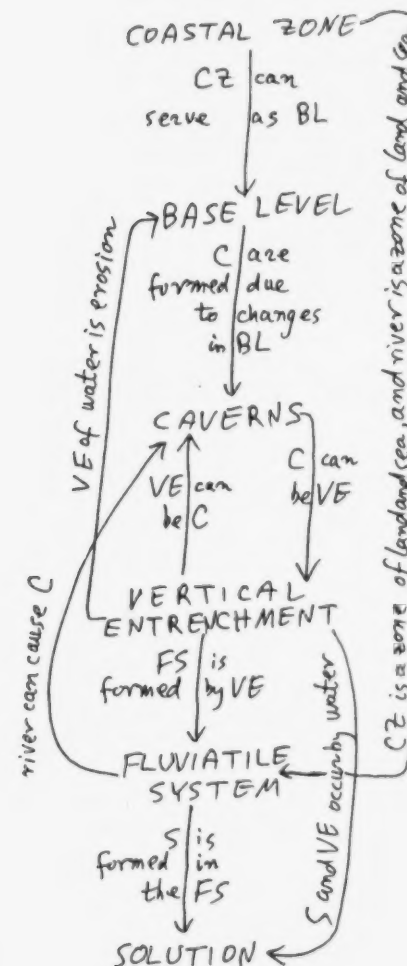
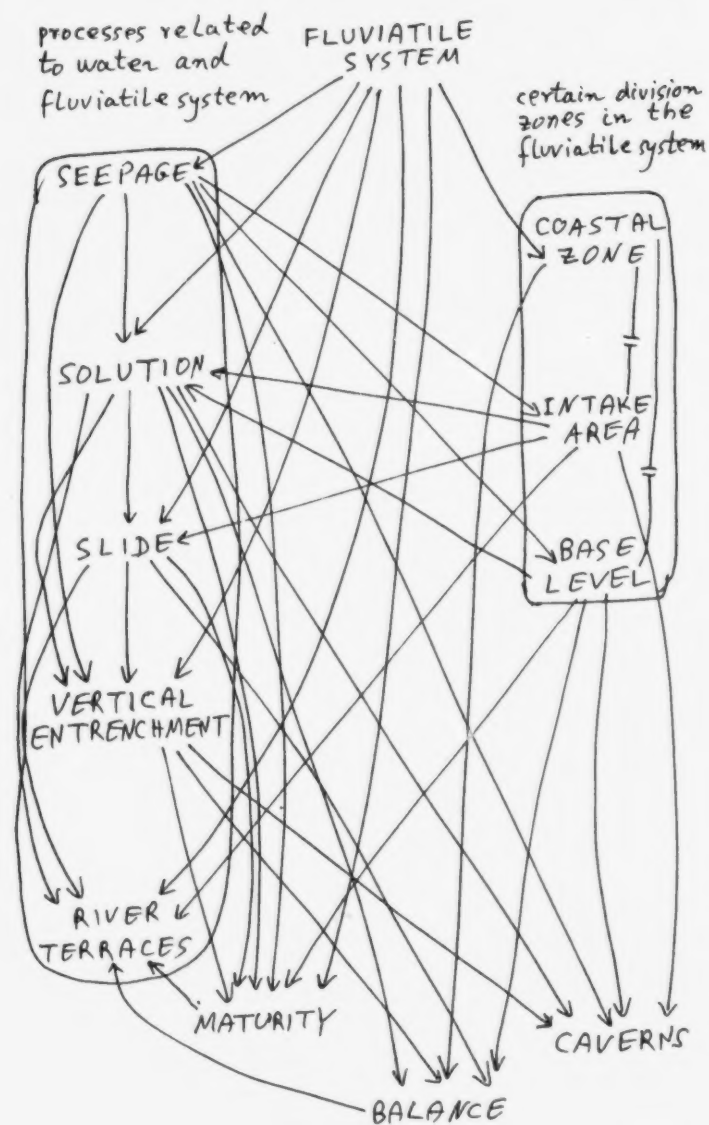


Figure 2. Cognitive map with overconnections.



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Figure 3. Cognitive map with underconnections.

fluvial system; processes and products of external factors that affect the earth surface



a group of processes and concepts that are related to geomorphology

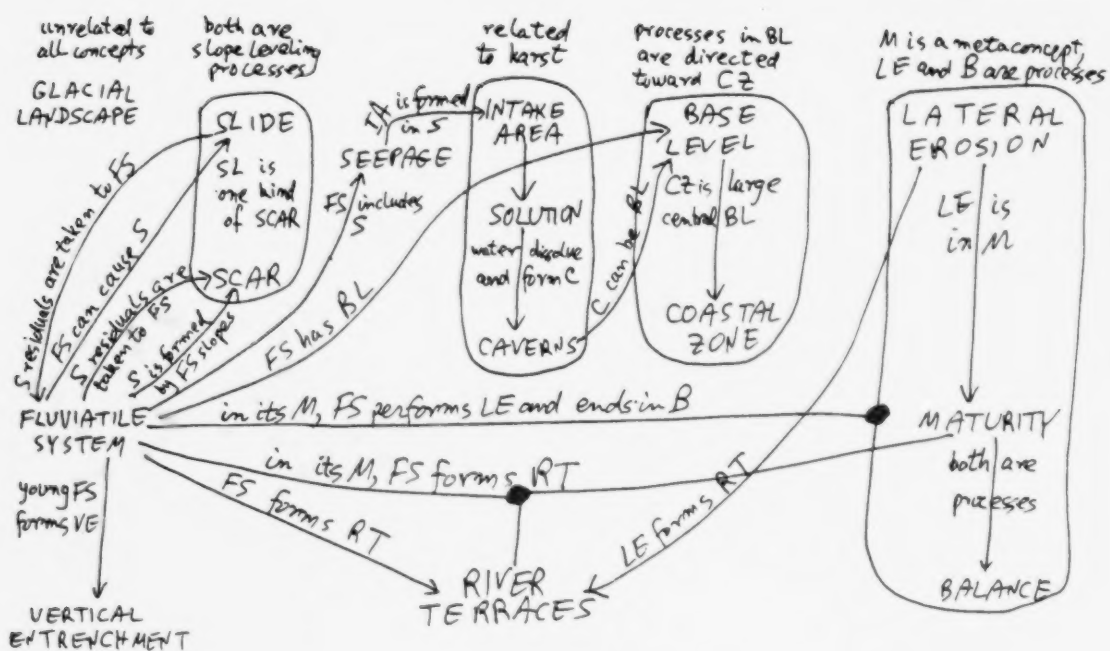


a group of landscapes



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Figure 4. Cognitive map with a large variety of misconceptions



THE STANDARD NORMAL DISTRIBUTION AND THE CALCULATION OF Z-SCORES: PITFALLS, MISCONCEPTIONS AND SOLUTIONS

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KEYWORDS: Continuous Distribution, Discrete Distribution, Correction for Continuity, Normal Distribution, Z-value.

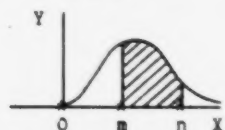
The standard normal distribution is of prime importance in statistics and, indeed, is a most useful tool for data analysis. Nevertheless, its applications are surrounded by many pitfalls. In this paper we point out some of these. We believe that social scientists should be very careful to examine the nature of the data with which they are working before they standardize these data and use the standard normal curve for further analysis.

Introduction

The standard normal distribution enables us to calculate proportions or probabilities associated with empirical data. This is so because the standard normal distribution can be fitted to these data. Data points are assigned z-scores according to a formula. Probabilities are then calculated by finding areas under the standard normal curve between z-scores.

Empirical data can be continuous or discrete. Continuous data can take on a continuum of values along the horizontal axis and are usually represented by a continuous frequency curve (see Figure 1a). Discrete data take on only discrete values and are usually represented by a frequency histogram, where the rectangles are centered at the (discrete) values and are one unit in width (see Figure 1b).

(a) Continuous Frequency Curve



(b) Frequency Histogram



Figure 1. Representation of Continuous and Discrete frequencies.

Areas under the continuous curve in Figure 1a and areas of rectangles in Figure 1b represent proportions of data in magnitude from m to n in Figure 1a and from r to s in Figure 1b. These proportions can be very easily approximated by superimposing or "fitting" a standard normal distribution to the empirical distributions in Figure 1a and 1b and then looking up the corresponding areas in the standard normal tables.

However, because of the histogram representation as in Figure 1b, discrete data present certain problems when we try to apply the (continuous) standard normal curve to the discrete data. This does not imply that we cannot fit the (continuous) standard normal curve to discrete data. Instead, we must account for this fact and correct for continuity. But first, let us distinguish between discrete and continuous data. Then we shall discuss the problems encountered by such in a section dealing exclusively with misconceptions.

Understanding Continuous, Discrete, and "Discrete-ized" Random Variables and Data

A basic question that the social scientist must address is, "Are the data continuous, discrete (or discrete-ized)?" Let us now clarify and distinguish among these terms and the reason for their importance.

Continuous data are data that can take on a continuum of values. A continuous random variable can take on any value with an infinite degree of precision between two given values. Examples of continuous random variables include: the amount of waste a plant produces daily; the weight of your father-in-law; and the amount of alcoholic beverage placed into a 341 ml beer can. How do you know if the random variable is continuous? The idea here is that continuous variables can assume any value between a maximum and minimum of limits (Horvath, 1985). In other words, regarding your father-in-law's weight, any value is possible, within limits. Theoretically, if weight were measured with an

infinite degree of precision then no two people would weigh the same. Generally, we do not achieve infinite precision. Horvath (1985) notes that "all real life measurement is expressed in discrete units, so that while some variables may be continuous, all actual data are discrete" (p.12).

Discrete data can assume only certain values such as whole numbers. A discrete random variable takes on a fixed or a countably infinite number of values. Examples of discrete variables include: the number of students standing at the main door of the Cornell University Library; the number of proofreading errors found in an approved doctoral thesis; and the number of violent crimes committed per month in Windsor, Ontario. How do you know if the random variable is discrete? The idea here is that the variable can take on a fixed or a countably infinite number of values.

Sometimes continuous variables are expressed in discrete units and hence, the term "discrete-ized" random variable simply refers to a continuous variable which has been made to be discrete. For example, the weight of your father-in-law can be described as a continuous variable when it is reported as 200 lbs, 15 ounces. This weight can also be described as a discrete variable when it is reported as 201 lbs. The difference between continuous and "discrete-ized" in this example shows that the level of accuracy (number of decimal places) is a factor to consider when changing from a continuous to a discrete one. The reason for distinguishing between continuous data and discrete-ized data is that if we are fitting a continuous distribution to discrete-ized data, we may have to correct for continuity. In turn, if we didn't recognize these data as "discrete-ized", we may assume they are continuous and overlook their need to be corrected for continuity.

We turn our discussion to pitfalls and misconceptions now.

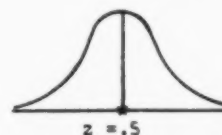
Pitfalls and Misconceptions in Using Discrete and Continuous Random Variables and their Distributions

Misconception 1: Not Distinguishing between Discrete and Continuous Distributions

The first misconception which may be stated is that discrete distributions and continuous distributions are not distinguished from one another. From this problem other misconceptions occur.

Misconception 2: Attaching a Probability to a Particular Point in Continuous Distributions

In continuous distributions we do not attach a probability to a particular point (Runyon and Haber, 1971). We cannot make such a statement as $P(X=1) = 0.5$ because probabilities in continuous distributions are represented by areas. There is no area between a point and the curve (or, if you wish, the line joining the point on the horizontal axis and the curve is viewed as infinitely thin, so that it has no area). Figure 2 shows this situation (Fraser, 1958, p. 63).



The line from $z = .5$ to the curve is infinitely thin. For practical purposes, it has no area.

Figure 2. Assigning a probability to a point in the Continuous case. $P(Z = .5) = 0$.

From Figure 2, a probability, such as " Z is less than .5" could just as well be stated as " Z is less than or equal to 0.5". Stated symbolically $[Z < .5] = [Z \leq .5]$. Since the normal curve is continuous, the area to the left of a particular ordinate and the area to the left of and including that ordinate differ by an infinitesimally small amount. Thus, in the continuous case, we need not worry whether or not "EQUAL TO" is or is not included in our statement.

Misconception 3: Representing the Area of a Point by a Line rather than by a Rectangle

In discrete distributions the mass is concentrated at a number of fixed points. We use a histogram to illustrate discrete distributions. Rectangles are drawn with the points of concentration as mid-points of the base. The respective heights of the rectangles represent the proportion of the mass concentrated at these points. The widths of the rectangles are conveniently taken as equal to one. For example, in the binomial case of answering true or false to two items on a test, the probability of getting half of the questions correct is 0.5 ($P(X=1) = 1/2$). Figure 3 shows this situation. Note that the point (rectangle) labelled with the number 1 is shaded to illustrate the rectangle.



Figure 3. Assigning a probability to a point (rectangle) on the horizontal axis in the Discrete case.

Misconception 3 arises when we are dealing with discrete distributions and are assuming that a line plays a role in cutting off the distribution as it does in continuous distributions. The fact of the matter is that in discrete distributions, we are dealing with rectangles rather than lines. The rectangles have width. Therefore, rectangles play a role in dividing scores in discrete distributions as opposed to lines in continuous distributions. Thus we can fit normal curves to discrete data if we properly take into account that probabilities or proportions, concentrated at discrete points are represented by areas of rectangles.

Figure 4 a represents the assumption of continuous data and Figure 4 b represents the assumption of discrete data.

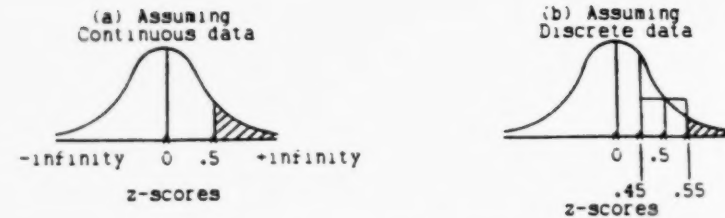


Figure 4. Comparing Continuous and Discrete Distributions.

Comparing these two distributions, the area > 0.5 in the continuous case is equal to the area ≥ 0.5 . From Table A (see Appendix A), this raw score produces an area of 0.3085 (.5000 - .1915). However, in the discrete case, the area > 0.5 is not calculated in the same way. Assuming our discrete raw scores are in units of tenths, each tenth representing an area, 0.5 includes all possibilities from 0.45 to 0.55. Therefore, in the discrete case, the line representing 0.5 does indeed depict an area of raw scores from 0.45 to 0.55 inclusive. After this fact is taken into account, the normal curve can be utilized as is done with continuous data. Calculation, in the discrete case, of the area greater than 0.5 is then done by considering 0.55 and the area beyond that number. Hence the area, if our raw scores are the same as z-scores, would be .2912 (.5000 - 0.2088) as opposed to the continuous case previously stated as 0.3085 (see Table A in Appendix A).

In sum then, we need to specify our cut-off points in the discrete case before we apply continuous procedures to it.

A special case will be considered as a topic next and then discussion will focus on specifically using a Correction Formula.

Misconception 4: Establishing a Convention to Accommodate a Special Case in Discrete Distributions

Some authors attempt to treat discrete data in the same way as continuous data. They assign a z-score to a discrete point and calculate probabilities by using areas to

the left or right of a line drawn from the point to the normal curve. They even attempt to establish conventions for dealing with anomalous cases. Horvath (1985) establishes a convention by stating "...the cutting score, or dividing line score, is always part of the area toward the mean of the distribution." (p.79). Figure 5 represents this situation.

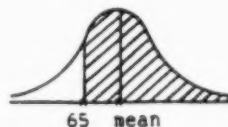


Figure 5. A Convention to establish the placement of the score which is on the line.

From Figure 5, the raw score 65 by convention is assumed to be part of the area toward the mean represented by the shaded area. This appears to be correct; but, what is failed to be realized is points along the horizontal axis in a discrete distribution are represented by rectangles, not by lines. These units represent areas because they are rectangles which by definition, have width (in contrast to the continuous case of a line).

In Figure 6, we see that the discrete raw score of 65 neither belongs to the area to the right of 65 nor does it belong to the area to the left of 65. The raw score 65 actually belongs to an area depicted by a rectangle which includes raw scores of 64.5 to 65.5 inclusive. This rectangle is illustrated by the shaded area (see Figure 6).

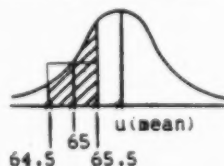


Figure 6. Area representing a discrete random variable which lies on the cutting edge of the line.

Therefore, we need not establish a convention to accommodate a special case in discrete distributions because a datum in a discrete distribution is represented by a

rectangle and a datum in a continuous distribution is represented by a line.

We conclude this section on misconceptions and focus our attention on the Correction Formula.

The Correction Formula

In order to obtain accurate answers to solutions involving the use of the standard normal distribution with discrete distributions of data, we need to correct for continuity (Freund, 1964). This we do by adding or subtracting one-half of a point one more decimal place to the raw score. For example, if we had a raw score of 6, the corrected raw score would be 6.5 or 5.5 dependent upon which side of the raw score the area under consideration lies. In tabular form we have:

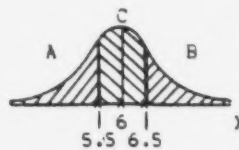
Table 1

Formula for Correction of Continuity

Formula	
$Z = \frac{X \pm \text{correction factor} - \mu}{\sigma}$	
Explanation of Symbols	
Z	= Z-score corrected
X	= original raw score
correction factor	= one half of a decimal place
μ	= mean
σ	= standard deviation

It seems appropriate that we answer here the question "When do we add the correction factor and when do we subtract it?" As an example, if we are considering areas of a discrete distribution that are greater than 6, we would add the correction factor. As a result, the area depicted by the Z-score would represent raw scores of 6.5 and greater. If we were considering the area representing raw scores less than 6, we would subtract the correction factor so that we would obtain a corrected raw score of 5.5. As a result, applying the (continuous) standard normal distribution would

now be done correctly and the area would represent raw scores of 5.5 and lower. Figure 7 displays areas of this discrete distribution.



Area A = $X < 6$
Area B = $X > 6$
Area C = $X = 6$

Figure 7. Areas depicting "greater than", "less than", and "equal to" the discrete raw score.

Table 2 represents a decision chart which includes all of the possibilities for use of the correction factor to be applied to discrete random distributions.

Table 2

Decision Chart for Addition or Subtraction of Correction Factor

Location of Area Under Consideration	Arithmetic Operation on the Correction Factor
$> X$	+
$\leq X$	+
$< X$	-
$\geq X$	-

Use of the Correction Formula is now illustrated.

Using the Correction Formula

Three examples will be presented in this section which all contain discrete data. Differences between correcting for continuity and not correcting for continuity are shown.

Example 1: The University Library

For this problem, let us now assume you are standing at the main door of the Cornell University Library. We will also assume that inside the library you are equally likely to find both male and female students. The question is this, what is the probability that of the next 6 students

to exit the library that more than 4 will be male? (mathematically, the probability is .1094). Also, what is the probability that more than 3 will be female? (mathematically, the probability is .3437). Appendix B gives the mathematical solutions to these problems but, we wish to utilize the normal curve to approximate these probabilities. Figure 8 represents the binomial distribution of this example.

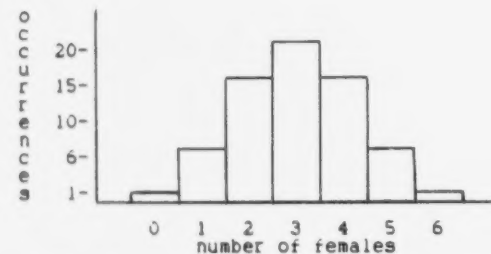


Figure 8. Binomial Distribution of number of females exiting the library.

In order to solve this example and others we must first ask ourselves, "Does this distribution consist of discrete or continuous raw scores (data)?" Since it consists of discrete data we must correct for continuity but first, let us illustrate what happens when correction for continuity is not made.

Incorrect Solution [> 4 males]

$$z = \frac{X - \mu}{\sigma} = \frac{2 - 3}{1.22} = -0.82$$

* Note: > 4 males means " < 2 females"
* Note: see Appendix B for calculations of μ and σ .

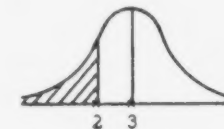


Figure 9. Portraying the incorrect solution whereby the shaded area represents the probability of raw scores < 2 .

Table A (see Appendix A) yields an area of .2939 for the z-score of 0.82. We subtract it from .5000 to obtain a probability of .2061 that more than 4 will be males. Contrasting this incorrect procedure to the mathematical calculation (see Appendix B) we get an error of 46.92%.

Calculating (incorrectly) the other half of the question:

Incorrect Solution [>3 females]

$$z = \frac{X - \mu}{\sigma} = \frac{3 - 3}{1.22} = 0.00$$

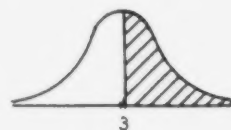


Figure 10. Portraying the incorrect solution whereby the shaded area represents the probability of raw scores > 3.

From Figure 10, we easily see the probability (proportion of 1) is equal to .5000 that more than 3 will be female. Contrasting this incorrect procedure to the mathematical calculation (see Appendix B), we get a difference of 31.26 %.

This is the correct way to calculate the z-scores :

Correct Solution [>4 males]

Formula

$$z = \frac{X \pm \text{correction factor} - \mu}{\sigma}$$

Application

$$z = \frac{2 - 0.5 - 3}{1.22} = -1.23$$

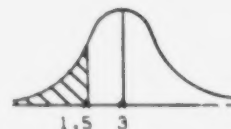


Figure 11. Using the Correction Formula whereby the shaded area represents the probability of discrete raw scores < 2.0.

Table A yields an area of .3907 for a z-score of 1.23. We subtract it from .5000 to obtain a probability of .1093 that more than 4 will be males. Contrasting this correct procedure to the mathematical calculation (see Appendix B) we get a difference of only 0.09% suggesting that this correction formula is very accurate. Calculating the other half of the question:

Correct Solution [>3 females]

Formula

$$z = \frac{X \pm \text{correction factor} - \mu}{\sigma}$$

Application

$$z = \frac{3 + 0.5 - 3}{1.22} = 0.41$$

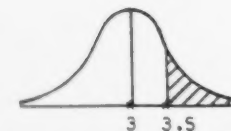


Figure 12. Using the Correction Formula whereby the shaded area represents the probability of discrete raw scores >3.0.

Table A (see Appendix A) yields 0.1591 of which we subtract it from 0.5000 to obtain a probability of .3409 that more than 3 will be females. Contrasting this correct procedure to the mathematical calculation (see Appendix B) we get a difference of 0.81%. A summary table is provided next.

Table 3

Summary Table of Results Contrasting Correction Without Correction

Procedure	Results	% Error
1 - No correction used	.2061 / .5000	46.92 / 31.26
2 - Correction used	.1093 / .3907	0.09 / 0.81
3 - Mathematical calc.	.1094 / .3437	0.00 / 0.00

Table 3 clearly shows the difference between correcting for continuity and not correcting for continuity. Example 2 is now presented.

Example 2: Lever-Pressing

After shaping 100 white-hooded rats to lever-press for food pellets, we wish to seek the number of rats who pressed the bar 10 times or less during an extinction phase. The experimenter has obtained data on rats' performance from other studies and these data yielded an average of 12 bar presses during the extinction phase with a standard deviation of 3 bar presses. Without considering the correction for continuity, calculations would proceed incorrectly as follows:

Incorrect Solution

$$z = \frac{X - \mu}{\sigma} = \frac{10 - 12}{3} = -.67$$

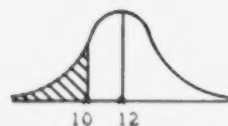


Figure 13. Portraying the incorrect solution whereby the shaded area represents the probability of raw scores ≤ 10 .

The probability would then be found by looking up the value for $z = -.67$ in Table A (Appendix A). This yields an area of .2486 of which we subtract from .5000 to obtain a probability of .2514 that the rats will press the bar 10 times or less during the extinction phase. We multiply this by the total number of rats to obtain our solution: $100 \times .2514 = 25$ rats pressed the bar 10 times or less during the extinction phase. However, this is an incorrect solution.

In order to obtain the correct solution we need to apply the correction for continuity as outlined earlier.

Correct Solution

Formula
$z = \frac{X \pm \text{correction factor} - \mu}{\sigma}$
Application
$= \frac{10 + 0.5 - 12}{3} = -.50$

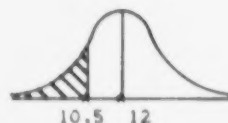


Figure 14. Using the Correction Formula whereby the shaded area represents the probability of discrete raw scores ≤ 10 .

The probability would then be found by looking up the value for $z = -.50$ in Table A. This yields an area of .1915 of which we subtract from .5000 to obtain a probability of .3085 that the rats will press the bar 10 times or less during the extinction phase. We multiply this by the total number of rats to obtain our solution: $100 \times .3085 = 31$ rats pressed the bar 10 times or less during the extinction phase. This is the correct solution as opposed to 25. The third example is now presented.

Example 3: The Self-Referent Content of Autobiographies.

This example will show three different procedures for solving the same problem. The FIRST PROCEDURE does not make use of the correction formula. The SECOND PROCEDURE produces the correct solution to the problem and employs the correction formula. The THIRD PROCEDURE contains one author's incorrect way of solving the problem. In order to compare the differences in the three procedures used, a summary table is provided. Let us now examine the problem and the various procedures used.

Suppose we were examining the number of words referring to the self in autobiographies. These words, such as "I", "me", "mine", etc. were counted for 2000 autobiographies. These data yielded normal distributions with $\mu=290$ and $\sigma=38$ for the 2000 autobiographies. We wish to find the number of autobiographies with 200 or fewer self-referent words per chapter.

First Procedure

In the first procedure, it would be tempting to calculate the z-scores in this way; however, it would be incorrect.

Incorrect Solution

$$z = \frac{X - \mu}{\sigma} = \frac{200 - 290}{38} = -2.37$$

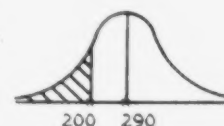


Figure 15. Portraying the incorrect solution whereby the shaded area represents the probability of raw scores ≤ 200 .

The area under the normal curve is equal to .0089 which is multiplied by 2000 (the number of autobiographies). The result is 17.8 autobiographies having 200 or fewer self referent words per chapter.

Second Procedure

In the second procedure, it would be correct to calculate the z-scores in this way:

Correct Solution

Formula
$z = \frac{X \pm \text{correction factor} - u}{\text{sigma}}$
Application
$z = \frac{200 + 0.5 - 290}{38} = -2.36$

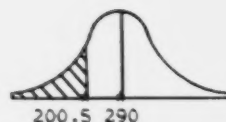


Figure 16. Using the Correction Formula whereby the shaded area represents the probability of discrete raw scores ≤ 200 .

The area under the normal curve is equal to .0091 which is multiplied by 2000 (the number of autobiographies). The result is 18.2 autobiographies having 200 or fewer self referent words per chapter.

Third Procedure

This procedure makes use of a method in which the next number is used. The idea is nearly correct but discreteness is not taken into account. The desired area is ≤ 200 , and the number 201 is used to obtain an area which depicts < 201 which is assumed to be 200 or less. The fact of the matter is that the line has area because, by definition, it has width. It is two-dimensional. It is true that $\leq 200 = < 200$ in the continuous case but in the discrete case, ≤ 200 is corrected by adding 0.5. However, the z-scores were calculated incorrectly as follows:

One Method
$z = \frac{(X + 1) - u}{\text{sigma}}$
Application
$= \frac{200 + 1 - 290}{5} = -2.34$

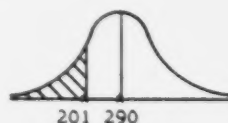


Figure 17. One Method of handling the correction for continuity whereby the shaded area represents the probability of raw scores < 201 .

The area under the normal curve is equal to .0096 which is

multiplied by 2000 (the number of autobiographies). The result is 19.2 autobiographies having 200 or fewer self-referent words per chapter.

In order to compare the difference in answers among the three procedures, a summary table identified as Table 4 is provided next.

Table 4

Summary Table of Results Using Three Different Procedures

Procedure Number	Results	% Error
1 - No correction used	17.6	2.19
2 - Correction used	18.2	0.00
3 - Incorrect procedure	19.2	5.49

Table 4 shows that using an incorrect procedure (procedure 3) to correct for continuity (in discrete data) may produce an even larger error than not using a correction formula (procedure 1).

Discreteness Approaches Continuity

It should be noted that to use the Correction for Continuity, we add or subtract one-half of a point one more decimal place to the raw scores. Hence, in adding the correction, 1.0 would become 1.5 and in subtracting the correction 1.0 would become 0.5. Other examples are as follows: 2.50 would become 2.55 or 2.45; 4.665 would become 4.6655 or 4.6645, and so on.

We conclude this presentation by showing what happens when data are given to more and more decimal places. We illustrate by two examples. The first example (Example 4) uses data which consist of whole numbers. The second example (Example 5) uses data with one decimal place.

Example 4. Students' Grades (as whole numbers)

Suppose we are given a set of student marks and we are asked to convert them to z-scores. The marks in this set are given to integral values only. Moreover, suppose that the mean is equal to 63 and the standard deviation is equal to

5. Finally, suppose we are asked the question "WHAT PERCENTAGE OF STUDENTS WILL HAVE MARKS BETWEEN 60 AND 70 INCLUSIVE?" The correct answer is 69.12%.

It would be tempting to calculate the z-scores in this way:

Table 5

Incorrect Calculation of z-scores.

$z_1 = \frac{60-63}{5} = \frac{3}{5} = -.6$	$z_2 = \frac{70-63}{5} = \frac{7}{5} = +1.4$
---	--

It would then follow that to find the designated area, first look up the area for $z = -.6$ (in Table A). This gives you 0.2257, which is 22.57% and which represents the area from the mean to $z = -.6$ (or area in Section A). Then, look up the area for $z = +1.4$ which is .4192. This gives you 41.92% which represents the area from mean to $z = +1.4$ (or area in Section B). Adding the two yields: $22.57 + 41.92 = 64.49\%$. Figure 18 shows this area.

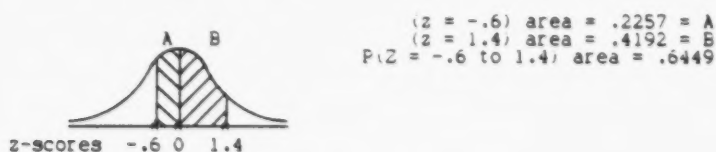


Figure 18. Non-corrected Result: Area between $z = -.6$ to $z = 1.4$.

Technically speaking 64.49% is an incorrect answer. In fact, many statistical textbooks provide such solutions. The z-scores of the extremities should be calculated as follows:

Table 6

Calculation of z-scores using the correction formula.

$z_1 = \frac{60 - 0.5 - 63}{5} = -1.7$	$z_2 = \frac{70 + 0.5 - 63}{5} = +1.5$
--	--

The required percentage of students having marks between 60 and 70 inclusive should be determined as follows: First, look up the area for a $z = -1.7$ in Table A (see Appendix A). This gives you .2580 which is 25.80% and represents the area from the mean to $z = -1.7$ (or area in Section A). Then, look up the area for $z = +1.5$ which is .4332. This gives you 43.32% which represents the area from the mean to $z = +1.5$ (or area in Section B). Adding the two yields: $25.80 + 43.32 = 69.12\%$. WHAT PERCENTAGE OF STUDENTS WILL HAVE MARKS BETWEEN 60 AND 70 INCLUSIVE? Thus, 69.12% is the correct answer. Figure 19 shows this area.

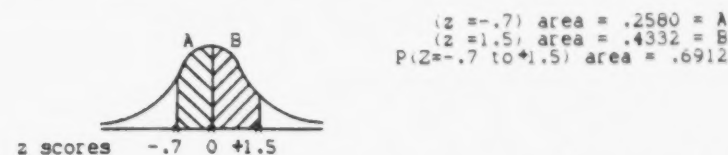


Figure 19. Corrected Result: Area between $z = -1.7$ to $z = 1.5$.

Another way of looking at the question is this. The instructor, by assigning integral marks, has effectively assigned to all marks between 59.5 and 60.5 the number 60. Likewise, the number 70 has been assigned to all marks between 69.5 and 70.5. Thus, effectively, the statement "all marks between 60 and 70, inclusive" would mean "all marks between 59.5 and 70.5 in the preliminary marking process before the final integral grades are assigned." Thus, the extremities 59.5 and 70.5 would be chosen for this problem. Figure 20 shows this situation.

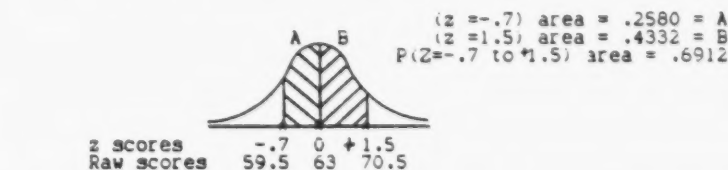


Figure 20. Portraying P ($Z = -1.7$ to $+1.5$) as Representing the Proportion of Raw Scores between 59.5 to 70.5.

What If?

A question which might be posed is this. "What if, indeed, an instructor assigns marks which may not be integral?" For instance, what if a student might receive a mark of 72.4, or 85.3 or 79 1/2, 85 1/4, etc.?

There is some hesitation by many instructors to use such fine division of marks because it fosters, in the minds of students, a perception of something trivial or of little account. However, if marking is pursued on this basis, the observations here are similar to the case where integral grades only are assigned and manipulations with z-scores are done in a similar manner.

For instance, let us take the case of assignment of decimal grades and apply an example.

Example 5. Students' Grades (with one decimal place)

Assuming the standard deviation for a set of scores was 5 and the mean was 80, "WHAT PERCENTAGE OF STUDENTS WILL HAVE MARKS BETWEEN 72.4 AND 85.3 INCLUSIVE?" The correct answer is 79.47% although it would be tempting to calculate the Z-scores in this way:

Table 7

Incorrect Calculation of z-scores.

$z_1 = \frac{72.4 - 80.0}{5} = -1.52$	$z_2 = \frac{85.3 - 80.0}{5} = +1.06$
---------------------------------------	---------------------------------------

The correct procedure is given next and involves using the Correction for Continuity. This results in the following correct solution:

Table 8

Correct Calculation of z-scores.

$z_1 = \frac{72.4 - 0.05 - 80.0}{5} = -1.53$	$z_2 = \frac{85.3 + 0.05 - 80.0}{5} = +1.07$
--	--

The areas would be:

NO-CORRECTION FOR CONTINUITY

(z = -1.52) area = .4357 = A
(z = +1.06) area = .3554 = B
Area = .7911 or 79.11%

CORRECTION FOR CONTINUITY

(z = -1.53) area = .4370 = A
(z = +1.07) area = .3577 = B
Area = .7947 or 79.47%

Figure 21 shows the appropriate area using the correct z-scores:

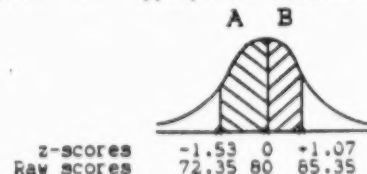


Figure 21. Portraying $P(-1.53 \leq z \leq +1.07)$ as representing the proportion of raw scores from 72.4 to 85.3.

It should be clear also that differences between uncorrected and corrected results decrease with an increase in the number of decimal places to which the data are given. For instance, in Example 4, where the data are given to integers the uncorrected result is 64.49% and the corrected result is 69.12%, a difference of 4.63%. In Example 5, where the data are given to one decimal place, the uncorrected result is 79.11% and the corrected result is 79.47%, a difference of .36%. Thus, the more decimal places in the data, the closer the discrete data is approximated by the continuous distribution. Hence, ultimately, if data is given to a sufficient number of decimal places, corrected results become negligibly different from uncorrected ones.

Synopsis

Social scientists, statistical textbook authors, instructors of statistics and students need to make clear distinctions between discrete and continuous distributions. As illustrated in this paper, misconceptions occur when discrete distributions are assumed to be continuous. In such situations, the usual correction formula for continuity is necessary but is often ignored. Thus, the resulting numerical value may be calculated incorrectly. We have noticed that few (if any) authors of statistical texts

either discuss or present this issue. It would be helpful if instructors and authors of statistical texts would clarify this type of application problem for the benefit of students.

In conclusion, it is suggested that a numerical index might be worked out to depict the degree of precision which the raw scores might take on. This index would give us an idea of the amount of error we would obtain when discrete data are treated as if they were continuous data.

References

- Fraser, D. A. S. (1958). Statistics: An Introduction. New York: John Wiley and Sons, Inc.
- Freund, J. E. (1975). Elementary Business Statistics: The Modern Approach. Englewood Cliffs, New Jersey: Prentice-Hall.
- Horvath, T. (1985). Basic Statistics for Behavioral Sciences. Toronto: Little, Brown and Company.
- Runyon R. P., and Haber, A. (1971). Fundamentals of Behavioral Statistics. Don Mills, Ontario: Addison-Wesley Publishing Company.

Appendix A

Table A

Area Under the Normal Curve (between u and z)

	.00	.01	.02	.03	.04	.05	.06	.07
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486
1.7	.2580	.2611	.2642	.2673	.2704	.2734	.2764	.2794
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.

* Note: to obtain an area beyond a z -score, simply subtract from .5000 the area given in Table A for that particular z -score.

Table A is an abbreviated version of the Area Under the Normal Curve. It is given here in order to aid readers in their understanding of the z -score's assumed conversion to the proportion of the area under the normal curve which is reported in the calculations given under each procedure.

Appendix B

Calculations for Example 1

I. The Binomial Distribution:

$$(q + p)^n = \sum_{x=0}^n C(n, x) q^{n-x} p^x$$

can be modified to:

$$(M + F)^6 = \sum_{x=0}^6 C(6, x) M^{6-x} F^x$$

to produce:

$$(M + F)^6 = C(6, 0) M^6 F^0 + C(6, 1) M^5 F^1 + C(6, 2) M^4 F^2 + C(6, 3) M^3 F^3 + C(6, 4) M^2 F^4 + C(6, 5) M^1 F^5 + C(6, 6) M^0 F^6$$

$$(M + F)^6 = (1)M^6 F^0 + (6)M^5 F^1 + (15)M^4 F^2 + (20)M^3 F^3 + (15)M^2 F^4 + (6)M^1 F^5 + (1)M^0 F^6$$

These results can be transformed into a table of frequencies (see Table B):

Table B

Frequencies of Males and Females in a Binomial Distribution

Number of Occurrences	Number of Females	Number of Males
1	0	6
6	1	5
15	2	4
20	3	3
15	4	2
6	5	1
1	6	0

II. Mathematical Calculations of probabilities:

Probability of more than 4 out of 6 being male:

$$= \frac{\text{number of occurrences of 5 or more males}}{\text{total number of events}}$$
$$= (1 + 6) / (1 + 6 + 15 + 20 + 15 + 6 + 1)$$
$$= .1094$$

Probability of more than 3 out of 6 being female:

```

= number of occurrences of 4 or more females
  -----
  total number of events
= (1 + 6 + 15)/(1 + 6 + 15 + 20 + 15 + 6 + 1)
= .3437

```

III. Calculation of Other Statistics

The mean and the standard deviation were calculated from these data : 0,1,1,1,1,1,2,2,2,2,2,2,2,2,2,2,2,2,2,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,4,4,4,4,4,4,4,4,4,4,4,4,4,5,5,5,5,5,6. The mean was calculated as 3 and the standard deviation was calculated as 1.22 .

MISCONCEPTIONS ABOUT MOTIVATION IN TEACHING

MATHEMATICS

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When motivation theory is applied to school learning, it provides a framework that stresses the developmental aspects of a student's motivation to learn and that, moreover, demonstrates how a student's motivational system and the own of the teacher are interlinked. Some aspects of the theory are applied to mathematics learning to demonstrate the usefulness of this theory.

The importance of motivation for the learning of mathematics is well accepted. Moreover, it is generally accepted that it is the teacher's responsibility to motivate his/her students.

Textbooks, written to prepare pre-service teachers for the challenging task of teaching mathematics, mostly deal with the issue of how to motivate students by stressing one or more of the following: good beginnings, life problems, recreational mathematics, math labs, etc.

Hardly any rationale for these suggestions are given, leaving the teacher alone to cope with the experience that his/her efforts sometimes seem to be successful, sometimes not.

Motivation theory, based on attribution, has been shown to be suitable to explain the development of a student's motivational framework relevant for

school learning in general. Moreover, this theory provides a basis that enables teachers to understand their role in the development of their student's motivational framework. A recent summary of relevant research results, geared for pre-service teachers, was done by Alderman et al. (1985).

Below are some highlighted aspects of the theory including some recent developments, which will give an idea of its relevance for the learning and teaching of mathematics in particular.

The readiness of a student to actually live up to his/her potential when given a mathematical task - that is his/her motivation to solve the task - depends on variables directly related to the situation; in particular, as to what degree the situational variables relate to the student's motivational framework, developed according to former experiences. Two of these variables are e.g. : the probability to be successful in solving the problem and the attractiveness of the task. Obviously the above suggestions for teachers can be looked upon as means to make the mathematical task attractive for students. But, if a student is convinced - due to former experiences - that

he/she will not be able to solve the task, he/she is very likely to avoid getting started no matter how interesting the problem is.

Table 1 gives an example (adopted from Heckhausen 1974) of a motivation process demonstrating the importance of cognitions involved in motivation and self-evaluation. The theory does not assume that these cognitions have to take place consciously each time.

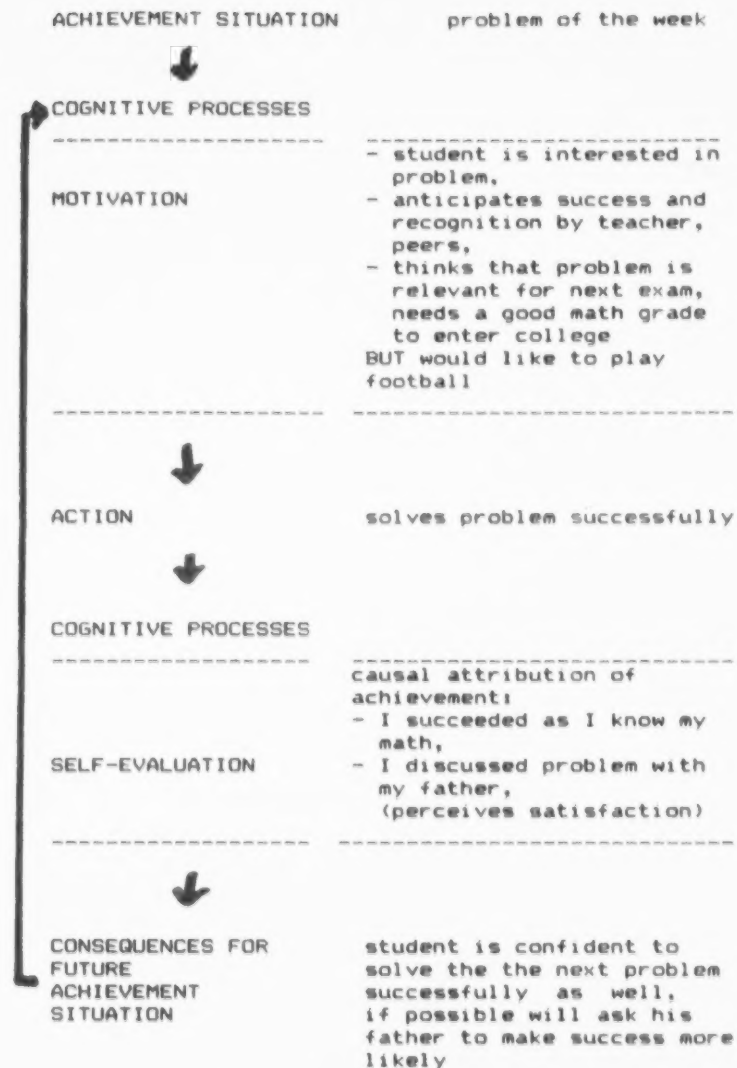
This particular example was chosen to demonstrate that

- a) the decision to sit down and solve a math problem normally is due to several motives - intrinsic and extrinsic ones,
- b) it is of crucial importance if and how the task is related to a student's long term project; e.g. if a student is determined to attend college and for this needs an A in math, he/she will make many efforts to reach this goal. In this case it could be irrelevant as to how interesting math is taught. The student might even prefer a teacher who only focuses on how to do the tasks relevant for the next exam.

Table 1

MOTIVATION PROCESS

Example



The model outlined in Table 1 not only describes the motivation process in one particular situation, but also when applied repeatedly - the development of a student's motivational framework.

Let us assume that a student repeatedly did not correctly solve the mathematical tasks given by the teacher. This has two impacts for the learning processes to come:

Firstly, a more subject-matter directed one: the student's deficiency lessens his/her chance of reaching the following goal because of his/her fragmentary antecedent knowledge. Commonly in mathematics the subject matter is hierarchical in nature and is taught in this way, hence accumulating deficiencies are likely to appear.

Secondly, a motivational directed one: failure can cause the student to make more efforts to compensate for these deficiencies and, if these efforts lead to success, the learning potential for continued learning is strengthened. If these efforts fail and if this occurs over and over again, a failure cycle is established (Shapiro 1962), in which the negative motivational development and the lack of knowledge relevant for the next learning step affect each other. In analogy to this failure cycle, a success cycle can be developed.

During the years at school a student develops a subject-matter related motivational framework including his/her achievement related self-concept and causal attributions of success and failure. These latter variables in connection with sex-role perceptions have been found as being useful in explaining sex-related differences in mathematical achievement and course-taking behaviour. It is in the research area of 'Women and Mathematics' that motivation theory based on attribution has been applied most frequently in math education (see e.g. Wolleat et al. 1980, Schildkamp-Kuendiger 1982, Eccles 1985).

In trying to understand the relationship between specific attributions, self-concept, and achievement, particular attention has to be given to

- 1) how each cause relates to the three main dimensions of these attributions. These dimensions are: causal stability, locus of cause and controllability (Weiner 1983, Hansen and O'Leary 1985). For example, effort can be perceived as a stable or unstable cause,
- 2) the motivational system a student has acquired, an aspect even more important for the school situation than the first one.

Ames and Ames (1984) focus on the latter aspect.

They define three systems of student motivation. These systems are: ability-evaluative, task mastery and moral responsibility. For example, in an ability-evaluative motivational system the student's attributional focus is ability-related and the self-evaluational and strategy focus can be characterized by questions like: "Am I smart enough? Can I do this?". For a student who acts on the basis of this system an effort attribution of math achievement means: "I am not smart enough, I need effort to succeed". This student probably will not choose to study math even if he/she is very successful in solving math problems.

On the other hand, for a student who acts on the basis of a task mastery system the attributional focus is effort-related and the self-evaluational and strategy focus can be characterized by: "Am I trying hard enough? How can I do this?" In this case an effort attribution of success indicates that a student will try harder in case of failure and will not easily give up because of perceived lack of ability.

The conceptual framework of a student's motivational system proposed by Ames and Ames seems to be extraordinary powerful for understanding the development of a student's self-concept of math ability. It seems to be worthwhile to re-

evaluate findings on sex-related differences in attribution patterns in light of this framework. Moreover, it presents a new view of the impact of teacher behavior that goes beyond the perspective of looking at the teacher as someone

a) who controls the difficulty level of math tasks,

b) who directly or indirectly influences his/her students attribution of their achievement. Instead, it might be possible by applying this conceptual framework to find out if the math learning environment created by a teacher promotes e.g. an ability-evaluative motivational system and if this math related environment differs from learning environments in other subjects.

Research in this direction is also likely to add a new perspective to sex-related differences in math achievement and course-taking behavior.

So far the role of the teacher has been looked upon as one of an outside agent in charge of the learning environment. In stressing that the teacher enters the classroom with a motivational system related to his/her ability to teach, Ames and Ames (1984) provide a framework for describing teaching and learning as an interactive process in which the teacher as a person is integrated.

Applied to mathematics this framework can form the

basis for research focusing on questions such as:

- In what way does a teacher's own math learning history that is his/ her math self-concept as a learning, influence his/her motivational system related to the teaching of math?
- How does the latter influence his/her teaching methods?
- Does a teacher - student circle exist, particularly in the primary grades? This could mean that a female teacher with a poor math learning history creates an ability-evaluative learning environment for her students in defense of her insecurity. This in turn, may have a negative effect particularly on her female students.

Some of the above questions are being investigated in a research project in Windsor (for first results s. Kuendiger 1985, 1987).

It seems that the importance of affect - related aspects in general, as well as the need for more elaborated frameworks has become more recognized in math education. Beliefs about mathematics and motivations related to the subject are more and more looked upon as important learning outcomes and less as factors promoting learning in a single instance only.

For example, at the PME- XI 1987 a whole series

of papers focused on beliefs, attitudes and emotions (McLeod 1987). Hopefully in the future these more complex views will be made available for teacher training as well.

Alderman M.K., Cohen M.W. (eds) (1985): Motivation Theory and Practice for Preservice Teachers, ERIC, Teacher Education Monograph No 4, CTE, Washington.

Ames C., Ames R. (1984): Systems of Students and Teacher Motivation: Towards a Qualitative Definition. In: Journal of Educational Psychology, Vol.76, 535-556.

Eccles J. et al. (1985): Self-Perceptions, Task Perceptions, Socializing Influences, and the Decision to Enroll in Mathematics. In: S.F. Chipman et al.(eds), Women and Mathematics: Balancing the Equation, Hillsdale, N.J. 95-122.

Hansen R. D., O'Leary V.E. (1985): Sex-Determined Attributions. In: V.E.O'Leary et al. (eds), Women, Gender, and Social Psychology, Hillsdale, N.J., 67-100.

Heckhausen H. (1974) : Motive und ihre Entstehung. In: F.E. Weinert et al. (eds), Paedagogische Psychologie Bd.1, Frankfurt, 133-172.

Kuendiger E. (1985): Perceptions of Pre-Service Teachers on Mathematical Achievement and on Teaching Mathematics. Results from a Pilot Study. In: C. Verhille (ed): Canadian Mathematics Education Study Group, Proceedings, Quebec 150-160.

Kuendiger E. (1987): The Mathematical Learning History of Pre-Service Teachers. In: J.C. Bergeron et al.(eds), Psychology of Mathematics Education, Proceedings of the 11th International Conference, Montreal, Vol III, 355-362.

McLeod D.B. (1987): Beliefs, Attitudes, and Emotions: Affective Factors in Mathematics Learning. In: J.C. Bergeron et al.(eds), Psychology of Mathematics Education, Proceedings of the 11th International Conference, Montreal, Vol.I, 170-183.

Schildkamp-Kuendiger E. (ed) (1982): An International Review of Gender and Mathematics, ERIC Clearinghouse for Science, Mathematics, and Environmental Education, Ohio.

Shapiro, E.W. (1962): Attitudes toward arithmetic among public school children in intermediate grades. Dissertation Abstracts, 22, 3927 f.

Weiner B. (1983): Some methodological Pitfalls in the Attributional Research. Journal of Educational Research, Vol. 75, 530-543.

Wolfeat P.L., Pedro J.D., DeVaney Becker A., Fennema E. (1980) : Sex Differences in High School Students' Causal Attributions of Performance in Mathematics. In: Journal for Research in Mathematics Education, 356 - 366.

Development of Expert Systems:

An Instructional Strategy for Dealing with Misconceptions

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If you want students to desire knowledge, then give them a reason. If you want students to understand content, then define the concepts. If you want students to see the usefulness, then let them try it. If you want understanding to lead to higher-level questioning, then let them create the questions!

1. Introduction

In our rapidly changing world with its intensifying focus on problem solving and expertise, new demands are constantly being channeled into the classroom. As scientific knowledge proliferates, information selection becomes more of a critical issue. Sadly, much of the way we talk and act about education still seems to presuppose an image of the student as a retainer of, rather than a processor of experience and information. We require students to memorize unintegrated bits of information rather than helping them refine and structure their knowledge by useful employment of it. We are more concerned with *what* answers are given than with *how* they are produced. Students therefore learn to solve problems by plugging given values into variables, and never adopt the conceptualization underlying the problem. As a result the principles, constraints and contextual issues inherent in the content are never really grasped -- and thus forgotten within a short time. This shortcircuits not only retention, but also transfer (Trollip & Lippert, 1987).

New computer technologies make it possible to deliver instruction in fundamentally different ways and allow for the possibility of radically different learning environments. Also, recent advances in understanding how students solve problems in the science disciplines have given researchers hope that new tools can be developed to improve the quality of science education (Linn, 1987). At the same time they provide researchers with far more powerful tools than ever to study how students learn.

Two of the main interests in science education research, misconceptions and problem solving, can benefit by using an instructional process and tool that artificial intelligence, in conjunction with cognitive science, have handed down to us. "It is clear that the application of AI research to education represents the potential for profound changes in trying to understand what the student understands." (Good, 1987). This paper proposes bringing some of the fruits of expert systems research to the conventional classroom,

discusses why the proposed technique may enhance and extend existing practices, and relates some initial experiences with its use. Features that will be discussed in this regard are the development of knowledge, problem solving, content structure, misconceptions, and the development of a learning strategy that is particularly conducive to the compilation, integration, and interaction of declarative and procedural knowledge.

2. Backdrop: Suggestions from recent work on misconceptions

(This backdrop is supplied for the express purpose of illustrating how the proposed new instructional process answers to past research recommendations.)

Good intellectual performance in science requires that scientific knowledge be used to solve diverse problems. Students need to learn about and practice scientific inquiry in such a way that they learn to develop questions and problems, recognize their own ideas and explore alternative ones (Osborne & Freyberg, 1985). In addition, students engaging in a social process of negotiating understanding of scientific data and of developing standards for inference, learn the definitions of variables, the range of variables considered, and the acknowledged interactions among variables that are appropriate in particular instances.

Reif (1987) discusses the inadequate concept interpretation of novice students. He mentions: 1) invocation of knowledge fragments, 2) lack of explicit applicability conditions, 3) knowledge storage versus processing, 4) lack of procedural interpretation knowledge, and 5) inconsistent and incorrect concept interpretations. To remedy this, he suggests active practice in applying this knowledge in diverse situations, using this knowledge to detect and diagnose mistakes and misconceptions. What must be some of the essential characteristics of knowledge to ensure that it can be used reliably and flexibly?

- 1) The knowledge must be coherent so as to ensure ease of remembering and the ability to make inferences.
- 2) Declarative knowledge must be accompanied by procedural knowledge that specifies what one must actually do to decide whether statements are true or false.

Otherwise declarative knowledge will be uninterpretable and ultimately meaningless.

2.1 Integration and organization of knowledge

Since inquiry and learning occur against the backdrop of current knowledge, assimilation and accommodation are important processes that govern the continual growth and refinement of cognitive structure. Conditions of accommodation dictate that adequate grounds for accepting new knowledge must take into account the character of the problems generated by its predecessor and the nature of the new theory's competition. There must be dissatisfaction with the existing conception, the alternative conception must be intelligible, initially plausible, and have extension potential. Integrated understanding is more likely to compete successfully with well-established, but inaccurate intuitive beliefs. For example, learners taught to reason about their new knowledge and to question how it fits with their current ideas gain greater understanding than those who are not encouraged to reflect on their own learning (Linn, 1987). Instruction focusing on complex skills such as planning problem solutions (such as CKB) can emphasize this self-regulation.

Both expert-novice and misconception research has suggested that a salient characteristic of a person's knowledge is the structure of that knowledge (inclusive of both content and its organization) and that it is possible to assess this cognitive framework (Driver & Easley, 1978; Champagne, Klopfer, Desena & Squires, 1981; Simon & Simon, 1977; Larkin & Rainard, 1984). Stewart, Finley, and Yarroch (1982) claim that structural organization of concepts not only makes current information more understandable and easier to assimilate, but also serves the learner in the acquisition of new knowledge. A concept may take on enhanced meaning by being embedded within and related to other concepts. The organization of subject matter knowledge is thus critical for later information retrieval.

Direct instruction in knowledge organization can be successful as for example when new knowledge is taught through elaboration (Eylon & Reif, 1984). But teaching rules and even cognitive structure has proven to be of limited success if students are not simultaneously taught when and why to use certain rules -- the so-called applicability and utility conditions (Lewis & Anderson, 1985).

2.2 Problem solving

There is ample evidence that skilled problem solvers operate from a different knowledge base than do less skilled problem solvers. They have more domain-specific knowledge of causal principles, and their knowledge is more likely to be organized around these causal principles. Furthermore, they have more prerequisite procedural knowledge and better knowledge of the conditions of application for various rules.

Studies of expert-novice differences in physics problem solving have found that experts use abstract principles to represent and solve a problem, whereas novices tend to base their representations and approaches on the literal or surface features of problems (Chi, Feltovich, & Glaser, 1981; Larkin, 1980). Experts evidently have discriminated when it is safe to rely only on surface features without accessing the deeper structure of the problem. Teachers and textbooks teach general rules, but provide no strategic advice about when to use them. Researchers like Larkin (1980) have found that teaching students the heuristics that experts employ pays off.

Lewis and Anderson (1985) state that problem solvers learn to apply appropriate actions from learning sets of problem features (schema) that predict the success of different problem-solving actions (operators). They maintain that students learn to apply an operator better during active, deliberate hypothesis testing. The degree of conscious processing affects how well schema are acquired. Operator schema are only formed when subjects actually incorrectly apply their operators and get feedback as to their errors.

Gagne and Smith (1962) found that instructing students to verbalize why they were making each move while solving a problem had significant effects on the number of moves and the overall time on task. Ericsson and Simon (1984) explain that verbalization forces subjects to make inferences about their mental processes and hence access information which would not be accessed if these inferences were not made.

2.3 Verbalization

Rumelhart and Ortony (1977) advocate generalization and discrimination as principal mechanisms for schema acquisition and modification. But these only describe schema changes, and are, in fact, not mechanisms for producing them. In highly integrated schemata a shift to a new paradigm via a dialectical process must also take place. Anderson (1977) believes that students participating in a Socratic dialogue are forced to deal with counterexamples to proposals and to face contradictions in their own ideas.

2.4 Conditional knowledge

Cues learners use to select problem solutions appear to become more relevant to the solution as expertise increases (Linn, 1986). This can be construed as planning knowledge which evolves with experience (Larkin, 1983). Students can be introduced to the criticality of knowledge of conditions and constraints by teaching it in parallel with new concepts and rules. In this way content and its structure is taught in an integrative way, instead of being left to the student to acquire intrinsically (Lippert, 1987).

2.5 Metacognition

How do people decide what to try next in solving a problem? How do they know when they understand something, and what do they know about what to do when they know they don't understand? Knowledge about knowledge and personal functioning is referred to as metacognitive knowledge. Lack of such strategic knowledge can seriously impede problem solving capability (Brown & Palincsar, 1985; Sternberg, 1982). Teaching an appropriate executive strategy to monitor and control one's efforts can enhance the problem solving

abilities of mathematics students (Schoenfeld, 1985). One mechanism for conceptual change would be to foster metacognition about solution selection during problem solving. Since learning is goal oriented, the learner must organize his or her resources and activities in order to achieve the goal. Flavell and Wellman (1977) suggest four general classes of metacognitive knowledge: 1) *tasks* -- knowledge about the way in which the nature of the task influences performance on the task; 2) *self* -- knowledge about one's own skills, strengths, and weaknesses; 3) *strategies* -- knowledge regarding the differential value of alternative strategies for enhancing performance; and 4) *interactions* -- knowledge of ways in which the preceding types of knowledge interact with one another to influence the outcome of some cognitive performance.

2.6 Misconceptions

The general agreement amongst researchers in the area of misconceptions is that effectual conceptual change is wrought by exposure or diagnosis, modification via ideational conflict, and lastly, a concerted and active phase of accommodation and consolidation. This is in agreement with the information processing paradigm which eschews a generative and constructivist model of learning.

The existence of a misconception (however localized or pervasive in its extent or effect) is attributable to a misconstruction, misrepresentation, or misappropriation of a certain segment of the subject-matter structure. Champagne, Gunstone and Klopfer (1985) mention that the characteristics of the declarative knowledge of beginning physics students include poorly differentiated and uncoordinated concepts, imprecise propositions (eg. more force means more speed), situation-specific explanatory schemata, and a poignant absence of principles.

Diagnosis of misconceptions demands a retrieval of a representation of a portion of the subject-matter structure in cognitive structure. As such it permits the examination of: 1) the property lists which give meaning to various

concepts, and/or 2) the overlap of property lists associated with pairs or groups of concepts, 3) the various relationships between concepts, and 4) the decision strategy used in selecting or evaluating concepts in longterm memory. Various techniques currently available to depict how students relate pairs of concepts, order concepts into larger structures, and how this activity affects the acquisition and understanding of new knowledge, are for example:

- 1) CONSAT: Concept Structure Analysis Technique by Champagne, Klopfer, Desena and Squires (1981).
- 2) CONSID: Concept Structure Interrelatedness Competence by Whaley and Novak (1964).
- 3) Concept mapping and Vee mapping by Novak (1981), and Novak, Gowin and Johansen (1983).
- 3) Concurrent and retrospective thinking-aloud protocols using word pairs, multiple choice questions with space for justification of choice, sorting, graph construction, free recall, and problem solving. Eg. Larkin (1980), Simon and Simon (1977).
- 4) Interviews about instances or events, parts of which have been called the DOE technique (Demonstrate, Observe, Explain)

While a useful body of knowledge is accumulating on students misconceptions in science, less is known about how to change those intuitive ideas (Osborne & Freyberg, 1985). Eradicating a misconception cannot be done by merely changing or deleting a single fact or concept or rule, but demands a much more pervasive action due to the multitude of interrelationships of these entities. It is not just a localized sanitation, but reorganization of the entire propositional network.

Conditions for successfully building on students' intuitive ideas (be they right or wrong) require that teaching must present new ideas in a plausible, intelligible, and fruitful way. Intelligible, in that it appears coherent and internally consistent; fruitful, in that it is perceived as elegant, parsimonious and useful.

3. The process of constructing a knowledge base

To the question, why use the construction of knowledge bases as an instructional tool, the following answers can be given. It is a vehicle to teach students:

- 1) Critical thinking through active employment of analysis, synthesis, and evaluation.
- 2) To think about their own thinking (metacognition).
- 3) To integrate knowledge within and between domains.
- 4) To cultivate conditional knowledge by thinking not only about "what" and "how", but to carefully weigh "when" and "why" (conditions and constraints).
- 5) Decision making in a variety of contexts, using probabilities and heuristics, by combining both qualitative and quantitative evidence.
- 6) To uncover and determine relationships, patterns, and correlations.
- 7) To formulate and solve problems of design and analogy, rather than mere transformation or manipulation.
- 8) To reason qualitatively, instead of relying on number crunching.

Before I attempt to argue the utility of this process for the prevention, diagnosis and remediation of misconceptions, let me describe the implementation of it. The teacher selects a topic that typically is hard to master due to its complexity by virtue of its abstract nature or its interrelationships with other topics. Depending on the goal of the exercise, the teacher sets a boundary to the size of the knowledge base, which essentially determines how many rules students will have to incorporate in the rulebase and to what level of specificity components will be described and dealt with. The prime task for the student is to isolate the essential decisions that can be arrived at when one considers the topic. These then dictate what questions need to be formulated, so that their answers lead to the decisions. The final task is to set up a procedure by which the links between question answers and intermediate decisions lead to the final decisions. This procedure is constituted of individual rules in a condition-action (IF-THEN) format, also called productions.

The teacher introduces the concept of an expert system, explains the format and structure of IF-THEN rules, and the logic behind the use of mathematical set theory to construct negations (NOT), conjunctions (AND) and disjunctions (OR). Students are assigned to groups of two to four, and begin by isolating and collecting the information that must be structured into a knowledge base. This is an iterative

process, as discussions amongst each other, with experts or consultants, or delving into the literature refine the focus and select the relevant issues. Typically this phase of identifying the content is the forerunner to the real exercise of debating about the priority, interrelationships, and sequence of material -- the stage of defining and exploring the representation and inferencing strategy.

The third stage involves assembling the knowledge base components: writing the questions, choosing the decisions, composing the rules and explanations. Language suddenly takes on great meaning since the need to be both succinct and accurate (as well as correct) surfaces. A real consideration underlies this concern: If someone else is going to use the system, will he or she be able to understand the logic, formulation and vocabulary? It is typically at this point that groups enter heated debates about representation of their collective understanding. It is a competitive effort to get it right, particularly when it comes to justifying a question or a rule by an explanation. In this feature individual comprehension is particularly salient.

On typing the components into the expert system shell and running the inference engine, the fourth phase, namely that of testing the representation begins. Frequently there will be errors of omission and redundancy, apart from syntax errors that can be easily identified and corrected. But just as often there will be an "Aha! Erlebnis" as students (as their own critics) discover the discrepancies in their thinking as depicted by inconsistencies and false inferences that they "unwittingly" engineered. They are betrayed before their own eyes and debugging becomes an in-depth search for completeness, consistency and correctness. Not all such errors are easy to remedy, since often the entire knowledge base has to be searched and remodeled to become more inclusive or coherent. At its worst, the knowledge base has to be architected from scratch. Typically this phase is accompanied by spatial representation of the content hierarchy, such as flowcharts and decision trees.

The final phase comprises retesting and verification, and then validation by public airing, either by letting someone use it and observing their responses and reactions, or by discussing it in a class setting (at which time quite a delightful dissemination of ideas and insights can occur). It is not uncommon that even after repeated refinement, a public airing can still uncover loopholes, thereby diagnosing deep seated misconceptions or other types of errors.

Building knowledge bases lends itself to a variety of instructional strategies.

- 1) With individuals, pairs, in teams of up to 4 students, or the whole class.
 - 2) The teacher as expert consultant or purely as manager.
 - 3) Only considering questions, or decisions, or rules, or the whole knowledge base.
 - 4) Students assigned to consult real experts, or to rely only on literature and their own knowledge.
 - 5) Knowledge acquisition by extraction solely from print or interfaced with experimental work in the laboratory or outside.
 - 6) As pen-and-paper exercise only, or also put into an expert system shell.
 - 7) As homework assignment over days, weeks, or a term.
 - 8) As revision, as enrichment or challenge, or instead of a paper or exam.
 - 9) As vehicle to primarily teach new knowledge, or as practice in problem solving and/or reasoning.
 - 10) Deliberate cross-fertilization by whole group evaluation of individual knowledge bases, or purely individualized activity.
 - 11) Integration of individual knowledge bases to a single product in whole group context.
 - 12) Students try out and critique each others expert systems by constructing the decision trees and checking the logic and consistency that way, or using the on-line versions and determining the completeness and correctness by posing as real users.
4. Methods by which the CKB can function in the service of misconception prevention, diagnosis and remediation

As indicated in the title, there are several roles that the CKB can assume. As an advance organizer, say as pre-exercise to a large unit, the process can diagnosis students prior knowledge, especially if students must design a knowledge base individually. As an integral part of an instructional unit, it can serve the students as learning tool, preventing careless assimilation by actually compelling

a more thoughtful processing amenable to accommodation. Of particular utility is the necessity to process the information in multiple representations (verbal, as well as pictorial such as concept maps, decision trees or flowcharts) thereby strengthening comprehension by sustained exposure.

Much has been said in the literature about the fruitfulness of peer tutoring and cooperative learning. As active mechanism to remedy misconceptions, the virtue of grappling with the issue in an intense style as in a group constructing a knowledge base, cannot be overlooked. Some pupils are more influenced by views and explanations put forward by other students, and this can be used to advantage. In fact, the burden on the teacher to deal with students individually is largely delegated to peers (who might be more ruthless, but might also have more effect). This is of course assuming that students actively participate and are not just passive onlookers. But then there are various strategies and incentives that the teacher can use to orchestrate competition and accountability. The teachers role in defining the teams (balancing the presence of strong and weak students) is needless to say critical to ensure healthy dialectics.

Seeing that conceptual change is usually a gradual process, and that the CKB can be conducted in a modular fashion, the teacher can assign the student to devise the questions, or any of the components, and by Socratic dialogue ensure coherency within components, before fleshing out the correlations and dependencies between components. This usually occurs when the rules are constructed, at which point the student can appreciate the full impact of his or her logic or knowledge.

To capture their erroneous beliefs graphically, the verdicts in the rulebase can be simulated practically to augment the CKB. If, for example, the topic is electric current, or gravitation, or light, experimental set-ups can function as showcases of the knowledge embodied in the knowledge base. ("You said: 'If resistors are placed in

parallel, then ...' Let's do it and see whether your rule holds up in real life.") With more abstract and intangible themes such as heat, this is obviously not possible and persuasion has to occur by logical argument.

4.1 A specific example

Physics problem-solving requires refined skill in isolating the relationships between important facts, and the conditions and constraints that dictate how these are configured. Aside from a good knowledge base, students need to have a lucid understanding of the organization of content matter in order to effectively use procedural knowledge in problem solving.

Standard textbook problems, based merely on recall, usually cater only for the direct application of one or more previously learned formulas. In contrast, process problems foster critical thinking and creativity, since they require non-algorithmic strategies that integrate various formulas and laws into a coherent unit. Take for example the revision of the classification of matter. If the teacher is anxious to know how students have integrated the theory and the practical experiments, the following Socratic procedure can be followed:

Students should volunteer the questions that need to be asked in order to come to a conclusion what a particular substance is. That could mean purely deciding on the state that a substance is in, or, more decisively, where it is classified on the periodic table (if it is an element), or what substances a compound is composed of. Students must be able to defend their propositions, that is, argue why these questions are important. They must know what possible answers could be given to such questions. Taking all possible combinations of answers, they must be able to project the plausible decisions. Or take the reverse order, given that say three decisions can be reached:

- D1 It's a solid.
- D2 It's a liquid.
- D3 It's a gas.

What questions need to be asked to come to such a conclusion? And why? What logical rules connect answers to decisions? Note that the number and content of decisions should be decided up front, in order to effectively define the domain, and restrict or adapt the size of the knowledge base to a desired instructional function and age group.

Q1: Is the substance a

- a1. solid?
- a2. liquid?
- a3. gas?

(Students could be led to see that a fourth option is possible: I don't know. How should such a response be incorporated? Or, what if the user of the knowledge system insists that it is a mixture of two states, or even all three? Is there also a fourth state?)

Q2: Is it

- a1. an element?
- a2. a compound?
- a3. a mixture?

(What concepts must students understand in order to distinguish between the answers to both questions? What will be gained from knowing a particular answer? That is, why is this question critical? Which question should come first: Q1 or Q2? Or, what should the next logical question be? What rules can be stated?)

R1: If Q1a1 and Q2a1 then Dx

If it is a solid, and an element, then ...

R2: If Q1a1 and Q2a2 then Dy

If it is a solid, and a compound, then ...

Here Dx and Dy stand for intermediate decisions in the process of establishing the final goals.

R3: If it is a liquid element, ...

R4: If it is a gaseous mixture, ... etcetera.

Explanations can be added to decisions and rules. Repeated "why" prompts during on-line questioning allow tracing of the logic chain logic (inference) built into the program explaining why a particular question or decision was given.

So far the knowledge base may look deceptively simple, but already these two questions and the connection between their answers will have elicited considerable thinking with such fundamental concepts as the kinetic theory, ratio of atoms, particle spacing, boiling or freezing points, separation mechanisms such as evaporation, etc., and not just mere thinking about concepts. Constructing knowledge bases thus forces students to think deeply and productively about the intrinsic characteristics and relationships of a topic.

It ought to be apparent that the instructional process outlined above confronts students with their own cognitive structure as they have to create a structural representation of what they have supposedly learned. It tests their declarative knowledge (eg. vocabulary), their conceptual knowledge (eg. how physical changes vs chemical changes implicate the state of matter), their procedural knowledge (eg. how classification can be conducted), and their conditional knowledge (when and why a certain process occurs or principle applies). As such it soon displays their misconceptions, or information that is absent or redundant. Before students can decide what question should be asked first, or why a particular question should be asked at all, (that is, the necessary and sufficient conditions), fundamental issues such as the hierarchy of the subject matter, and the interrelationship between the various knowledge elements (concepts) have to be clarified. As a vehicle to teach problem solving, students are confronted with the characteristic problem solving stages, namely 1) identifying and understanding the problem, 2) devising, planning, and exploring possible strategies, 3) acting on these strategies, and 4) evaluating their effects. Thereby students should be able to conceptualize, define, and analyze problems, seek out appropriate data, formulate key questions, discover patterns and similarities, transfer skills and strategies to new situations, and to become familiar with experimentation. They soon notice that there is more than one way of constructing a knowledge base, but that there are

certain strategic plans that limit the search space, that is, converge on the critical elements so as to reach a conclusion in the most efficient way possible.

The modular format of a production system is particularly amenable to cumulative assimilation of knowledge. For example, once students have mastered the rudimentary classification of matter, the knowledge base can be progressively extended to incorporate the structure of the periodic table, chemical bonding, atomic structure, etc. Students can thereby foreseeably integrate their entire learning in a domain. What's more, they can integrate their learning across domains, such as interfacing chemistry and physics, where there is a considerable overlap of principles and procedures.

4.2 Evaluation of Students' Knowledge Bases

What should be the criteria by which students' efforts are to be judged? It is very easy to detect simple-mindedness (a very linear flow) but harder to appraise the complexity of the knowledge incorporated into the knowledge base. The latter requires a careful analysis of the manifold relationships forged between knowledge elements.

Evaluation must always address both components evident in a knowledge base or expert system, namely the content and its organization. It is easier to assess the content than the structure, but typically it is the structure that students have most problems with. And it is the structure that is ultimately responsible for the change in students cognitive knowledge base — a main reason for the CKB process in instruction. Some helpful evaluation heuristics follow.

A. Size

Just looking at the size of the knowledge base is deceptive, since inference power usually does not lie in number of rules, but in the way that rules are formulated and ordered. Thus it is utterly possible that two equal sized knowledge bases can be poles apart: one posing only strategic questions, while the other only covering a small percentage of the questions possible in the particular domain.

B. Vocabulary and number of concepts

An appraisal of the number of basic concepts and the accuracy and relevancy of the terminology used gives a good hint of the coverage of knowledge in the knowledge base.

C. Number of questions per rule

The interrelationships of concepts and the depth of knowledge pertaining to a particular decision is illustrated by the amount of information called for to make that specific decision. This is of course in opposition with the well-known fact that true experts often make decisions on the basis of very little data, and often do so by sheer recognition procedures. With students, one is still dealing with novices in transition to experts. Criteria cannot be applied too strictly, since students displaying some measure of expertness in a given domain might have a smaller number of questions per rule, than someone who still deals with information very exhaustively. In the final analysis efficiency and effectiveness are the yardstick to use.

D. Number of top goals, and number of subgoals attached to each top goal

The extent of a domain under consideration is usually defined by the number of top goals (final decisions). Vital interrelationships are depicted by the number of intermediate decisions (subgoals) necessary for validation of a given final decision. This shows the nestedness of the domain. The logic construct of "necessary and sufficient conditions" becomes a valuable evaluation criteria.

E. Depth and breadth of the decision tree

A decision tree is a good visual aid to track not only the extent of the knowledge considered in the rulebase, but also serves to display the number of alternate answers and how these lead to different conclusions. A decision tree is essentially a navigation chart, showing lines of reasoning, alternate inferences, and various interrelationships.

F. Completeness

Are all the essential components represented? Look at the number of concepts and the nature of the decisions. Are

all possible cases within the domain accounted for?

G. Correctness

What answers are used to validate which decisions? Looking at the list of associations, are any misconceptions evident? Is the advice given by the expert system appropriate? What are the basic assumptions underlying the reasoning used by the expert system?

H. Coherency and Consistency

Are the relationships that were formed correct and complete? That is, do things hang together well, or does missing knowledge result in discontinuities or false conclusions? Is the same advice or prescription given for the same case at all times? Are any contradictions present?

I. Conciseness

Is there an apparent economy, elegance and smoothness of decision execution, or is the knowledge base loaded with redundant information? This can often be seen in the rulebase when large chunks of previously established goals and associated data are either repeated in subsequent rules or replaced neatly by the decision validated earlier. The designer's awareness of priority, hierarchy and patterns becomes evident in the way that the rules are formulated and ordered. It is the ordering of rules in particular that displays the designer's understanding of the structure of the knowledge under consideration.

5. Benefits of the construction of knowledge bases

If these then were some of the overt mechanisms in which the CKB can be incorporated into instruction concerned with misconceptions, what are the accompanying covert processes that the CKB addresses?

- 1) An awareness that actions and findings should be critically examined.
- 2) Clarity of what to look for, the importance of a result.
- 3) The perception of a purposeful and useful activity. It is a relevant activity since they have the freedom to be creative, bound only by the format of input of the text editor.
- 4) An awareness of own fundamental assumptions and of those implicit in scientific theory.

- 5) Students are accountable for their construct and can relate or explain their thinking and interpretation. The demand for consistency among their beliefs about the world are impressed upon them.
- 6) Some sense of the fruitfulness of new conceptions advocated by others in the group.

Posner, Strike, Hewson and Gertzog (1982) call for science to develop instruction that creates ideational conflict, as well as organizing instruction so that teachers have time to deal with students' misconceptions. They suggest representing content in multiple modes (verbal, mathematical, pictorial, concrete-practical) to aid students in the organization of their knowledge. Teaching aimed at accommodation should develop evaluation techniques to help the teacher track the process of conceptual change, and organize instruction so that teachers can spend a substantial portion of their time in diagnosing errors in student thinking and students' resistance to accommodation.

In my opinion the CKB fulfils all these suggestions. Individual students' analyses are elaborated and modified by other students analyses. Inevitably, controversies arise, usually identified because of differences in interpretation. Typically, students with alternative beliefs attempt to convince others of the validity of their ideas. As an individual or group defends a position, the concepts become better exposed and defined, and underlying assumptions and propositions are stated explicitly. The net result is that students are explicitly aware of their analyses of the situation and the need to reconcile it with scientific concepts and propositions (as set forth in the literature or the verdicts of experts in the field).

Students can't get away with making noises that s... scientific. Knowing phrases or terminology without understanding the conceptualization underneath them is soon exposed and displayed several times during construction; namely in decision trees and the formulation of questions, decisions, and encompassing rules.

The rule-base demonstrates tangibly whether students connect concepts in an integrated way, by what criteria they are grouped, what relationships students use to link concepts, whether these relationships are idiosyncratic or whether they conform to relationships specified by subject matter specialists. For example, students typically have problems with the simultaneous change of several variables, which often is the case in a dynamic process such as heat transfer, or conduction of current. The use of qualitative questions forces the student to consider the functional relationship between variables, since they cannot automatically apply algorithms in a mechanical manner. In the CKB they are tested on this score. If experts are characterized by the power of their qualitative heuristics that they employ in establishing a problem-solving strategy, the use of CKB would be a productive method to nurture this capability in students.

Verbalization is an important component in conceptual change. While students in groups of two or more decide on the content and structure of the knowledge base they are actually forced into a self-activating and sustaining Socratic peer tutoring mode. "What will happen if...?" and "Why will it happen?" and "Why do you say that this is a prerequisite/antecedent to this question or decision...?" and "In what order do you propose that these elements be placed?" and "What are the necessary and sufficient conditions for this to be true?" and "What are other alternatives to ...?" and "How can this be phrased unambiguously?" are typical questions and counterquestions that students would use in the dialectic process of coming to an agreement that synthesizes their individual understandings. In essence the process is an appeal to reflect, consider and critically judge conditions, constraints, actions and consequences, and to reveal these thought processes in the form of knowledge base components.

Group projects typically generate a tremendous amount of cooperative learning through peer interaction. These

intra-group interactions contribute to versatile cognitive growth because it is a direct confrontation with different interpretations. The public airing and defense of a system also provides an opportunity for cross-fertilization of creative ideas that is not readily available through other means. Much incidental learning takes place as students become focused researchers while extracting information from "experts" (print or humans). The rigor required in defining the rules forces students to read the literature in a very directed fashion, seeking answers in much the same way that advance organizers cause students to survey text. Intrinsic motivation is engaged through curiosity, conceptual conflict and challenge. Students see the consequences of their decisions and solutions, and thereby can become the interpreters of the extent and limitations of their own conceptualizations of reality.

From an information processing perspective I derive the following explicit predictions concerning the utility of CKB:

- 1) CKB consists mainly of elaboration and organization. Elaboration adds information, while organization adds structure to information. This has immediate benefits for encoding and retrieval.
- 2) Generalization and discrimination facilitate pattern recognition and action sequencing, which are two main manifestations of procedural knowledge.
- 3) Students will be able to communicate their problem solving in a systematic way, using a scheme that models scientific thought.
- 4) Students become much more aware of the dimensions and representation of a problem.
- 5) Analysis, synthesis, and evaluation are chief cognitive processes in CKB, thereby teaching students to reason.
- 6) The entire CKB procedure demonstrates a learning strategy that relies on lucid acquisition, representation, storage and utilization of knowledge.

5.1 Particular benefits to the student

In the construction of a knowledge base students are actively engaged in using knowledge of conditions and constraints to tie declarative and procedural knowledge together into a meaningful unit. As a problem solving task the CKB relies on a thorough synthesis of the content domain. This is the vital difference between solving a number of

problems hoping students come to a synthesis and cognitive organization themselves, versus giving them a task that forces them into a synthesis mode with contextual feedback as to their effectiveness in achieving it. Students are creative, instead of in rote, mechanistic problem solving.

5.2 Particular benefits for the instructor

Empirically the CKB carries some promise as a new teaching as well as learning strategy. It is a new process to trace changes in cognitive structure as a result of instruction, to explore the relationship between knowledge structure and problem solving, and to attune students to monitoring their own learning by deliberate metacognition. It is an instructional process that addresses the higher-order thinking skills in a rich way, allows for much individualization, and lastly promises to be a new way to identify and confront misconceptions. It is also a promising testing procedure to replace traditional tests that are insensitive to structure, errors of omission and intrusions.

Theoretically it allows new insights into learning of intellectual skills and cognitive representation and action. Thus it will have spin-offs for schemata and information processing theory. Greeno and Simon (1986) believe that human thinking can be modeled as production formation. This process can show how effective a deliberate attempt at having students think in condition-action format can be in normal instruction, and so contribute to instructional psychology, computer-based education, and cognitive science.

6. Research results

What effect does the new instructional process have on the integration and evolution of both declarative and procedural knowledge? Can the effect be attributed to the emphasis on conditional knowledge in the construction of a knowledge base?

The following excerpts are from a 1987 summer project in which various freshman physics students constructed an on-line knowledge base on projectile motion.

Q: "What have you learned about projectile motion as a result of the construction of this knowledge base?"

S1: "I learned new relations and new ways of organizing the information. I learned the mechanics of air resistance, what factors are involved. I know more definitely what to look at and for in problems, and in what order to consider things."

S2: "I've analyzed and organized my thinking. It's been so chaotic that up till now I've not been able to organize it and fit it together with everything else. It's more refined."

S3: "When I started I thought of projectile motion only in Cartesian coordinates, no air resistance, constant force field, etc. Now it's any object undergoing acceleration in any force field. Air resistance for example is rarely negligible."

Q: "How would you solve problems now, and what type of problems would you be able to solve now?"

S1: "I would look at the whole problem rather than just the equations. Before I would not have been able to handle a problem like an odd shaped thing falling with wind around and be able to draw force vectors and determine the path."

S2: "The idea I had before was that there is no air resistance, and now it's worked itself up to a much more complex system. Like how to handle the curvature of the earth and the Coriolis effect. I formerly knew just that gravity acted and something landed. Now it's a whole range of things that come into play. Usually I just put numbers into equations. Now I have a much better understanding where the equations come from, how they work, how they go together. The principles behind them."

S3: "The value of CKB is that you don't just learn how to use an equation, you learn how to solve realistic problems. The designer of the knowledge base to focus on all aspects, variables and their effects on the problem."

6. Summary

Many mistakes exhibited by students are traceable to knowledge that is fragmented and uninterpretable. The construction of knowledge bases aids refinement of domain-specific knowledge due to greater degrees of elaboration during encoding, greater quantity of material processed in an explicit, coherent context and thus processing in greater semantic depth. Elaboration greatly enhances encoding, which in turn interacts with retrieval, since "... how it is retrieved depends on how it was stored" (Tulving & Thomson, 1973). Spatial representation of knowledge during construction (via decision trees) and during validation (via flowcharts and dialogue traces) allows a recording, monitoring and assessment of students' dynamic cognitive organization, thus facilitating remediation.

The CKB approach illustrates the value of learning by doing with the learner as an epistemologist. It depicts the perception and understanding of the student: Is the domain seen as only a collection of odd and unconnected facts, as conflicting facts, or as a complex of interrelated quantities? Only when the formal structure of the problem is perceived correctly can missing data be appreciated, and surplus information draw attention to the necessary and sufficient conditions inherent in the interrelationships. Students can plot their decisions and associated rules in a tree-like format, as they respond to the prompts of the shell, thus seeing the hierarchical structure, subsumptions and branching they built. They can correct, expand or erase features and retest the rule-base over again — until they are persuaded that their representation is complete and correct. It is this facility that is unique as an instructional tool, and particularly attractive since it does not depend on the immediate presence of the instructor. Students are no longer spectators and imitators in problem solving, but engineer their own solutions (Lippert, 1987).

7. Conclusion

I believe that many of the processes involved in rational conceptual change and growth are inherent in the construction of a knowledge base. Tacit knowledge becomes salient, schema specialization and generalization takes place, attribute isolation leads to careful definition of terms and concepts, and a great deal of metacognition is involved as students explore the context and coherency of their own knowledge, while seeing others present ideas in plausible, intelligible and fruitful ways that lead to viable accommodation. It is a promising alternative to practice and drill that short change the development of vital cognitive skills that problem solving in real-life situations demand. When the CKB process is linked with experimentation and visual illustrations, the overall process emulates scientific inquiry. Conceptual change is a gradual process with no quick and easy solutions. The CKB too, is a tedious, though thorough process. What might ultimately vote in its favor is the enjoyment and meaningfulness of this procedure, as quoted from those that have gone through the process.

Lastly, CKB as an instructional strategy is a practical application of new technology, an integration of various research themes, has the potential to increase fundamental understanding of science learning, and to yield new views of teaching and goals for the curriculum.

8. Some further research questions

What is the nature and extent of the interaction between declarative, conditional and procedural knowledge in producing a clear understanding of content, which in turn facilitates problem solving skill? Are gains in these spheres related and/or comparable?

What factors play a role in the success of the CKB process as a problem-solving tool? Spatial ability, analytical ability, logical ability, familiarity with problem context and content? How is motivation to learn affected?

How is retention of facts and problem-solving skill effected over time?

How will this activity (if implemented over some weeks in a cooperative style) affect the socialization amongst students? What are the constraints on time and size of knowledge base for a given age group?

REFERENCES

- Anderson, R.C. (1977). Schooling and the acquisition of knowledge. Hilldale, NJ: Lawrence Erlbaum.
- Brown, J.S. & Palincsar, A.S. (1985). Reciprocal Teaching of Comprehension Strategies: A Natural History of One Program for Enhancing Learning. Center for the Study of Reading.
- Champagne, A.B., Gunstone, R.F., & Klopfer, L.E. (1985). Effecting Changes in Cognitive Structures Among Physics Students. In Leo. H.T. West, & A. Leon Pines (Eds.), Cognitive Structure and Conceptual Change. New York: Academic Press, Inc.
- Champagne, A.B., Klopfer, L.E., Desena, A.T., & Squires, D.A. (1981). Structural representations of students' knowledge before and after science instruction. Journal of Research in Science Teaching, 18, 97-111.
- Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and Representation of Physics Problems by Experts and Novices. Cognitive Science, 5, 121-152.
- Driver, R., & Easley, J.A. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. Studies in Science Education, 5, 61-84.
- Ericsson, K.A. & Simon, H.A. (1984). Protocol analysis: Verbal reports as data. Cambridge, MA: The MIT Press.
- Eylon, B. & Reif, F. (1984). Effects of knowledge organization on task performance. Cognition and Instruction, 1, 5-55.
- Flavell, J.H. & Wellman, H.M. (1977). Metamemory. In R.V. Kail & J.W. Hagen (Eds.), Perspectives on the development of memory and cognition (pp. 3-33). Hillsdale, NJ: Lawrence Erlbaum Associates.

- Good, R. (1987). Artificial intelligence and science education. Journal of Research in Science Teaching, 24(4), 325-342.
- Greeno, J.G. & Simon, H.A. (1986). Problem Solving and Reasoning. Handbook of Cognitive Science.
- Larkin, J.H. (1980). Teaching problem solving in physics: The psychological laboratory and the practical classroom. In D.T. Tuma & Reif (Eds.), Problem Solving and Education: Issues in Teaching and Research. Hillsdale, NJ: Lawrence Erlbaum.
- Larkin, J.H. (1983). A general knowledge structure for learning or teaching science. In A.C. Wilkinson (Ed.), Computers and Cognition. New York: Academic Press.
- Larkin, J.H. & Rainard, B. (1984). A research methodology for studying how people think. Journal of Research in Science Teaching, 21(3), 235-254.
- Lewis, M.W. & Anderson, J.R. (1985). Discrimination of Operator Schemata in Problem Solving: Learning from Examples. Cognitive Psychology, 17, 26-65.
- Linn, M. (1986). Science. In R.F. Dillon & R.J. Sternberg (Eds.), Cognition and Instruction. New York: Academic Press, Inc.
- Linn, M. (1987). Establishing a Research Base for Science Education: Challenges, Trends, and Recommendations. Journal of Research in Science Teaching, 24(3), 191-216.
- Lippert, R.C. (1987). Teaching problem solving with expert systems in science and mathematics. School Science and Mathematics, Fall.
- Novak, J.D. (1981). Applying learning psychology and philosophy of science to biology teaching. American Biology Teacher, 43, 12-20.
- Novak, J.D., Gowin, B., & Johansen, G.T. (1983). The use of concept mapping and knowledge vee mapping with junior high school science students. Science Education, 67, 625-645.
- Osborne, R. & Freyberg, P. (1985). Learning in Science: The implications of children's science. Portsmouth, N.H.: Heinemann.
- Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66, 211-227.
- Reif, F. (1987). Instructional Design, Cognition, and Technology: Applications to the Teaching of Scientific Concepts. Journal of Research in Science Teaching, 24(4), 309-324.
- Rumelhart, D.E. & Ortony, A. (1977). The representation of knowledge in memory. In R.C. Anderson, R.J. Spiro, & W.J. Montague (Eds.), Schooling and the acquisition of knowledge. Hillsdale, NJ: Lawrence Erlbaum.
- Schoenfeld, A. (1985). Mathematical problem solving. Orlando, FL: Academic Press.
- Simon, D.P. & Simon, H.A. (1977). A tale of two protocols. In J. Lochhead & J. Clement (Eds.), Cognitive Process Instruction: Research on Teaching Thinking Skills. Philadelphia: Franklin Institute Press.
- Smith, K.A., Starfield, A.M., & Macneal, R. (1985). Constructing Knowledge Bases: A Methodology for Learning to Synthesize. Proceedings of the 1985 Frontiers in Engineering Education Conference.
- Sternberg, R.J. (1982). Reasoning, problem solving, and intelligence. In R.J. Sternberg (Ed.), Handbook of human intelligence. New York: Cambridge University Press.
- Trollip, S.R. & Lippert, R.C. (1987). Constructing Knowledge Bases: A Promising Instructional Process. Journal of Computer-Based Instruction, 14(2), 44-48.
- Tulving, E. & Thomson, D.M. (1973). Encoding specificity and retrieval processes in episodic memory. Psychological Review, 80, 352-373.
- Whaley, R.M. & Novak, J.D. (1964). Conceptual schemes: Major items in the progress of science. In P.D. Hurd (Ed.), Theory into action. Washington, DC: National Science Teachers Association.

EXPERIMENT AS THE OBJECTIFICATION
OF THEORY: GALILEO'S REVOLUTION

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INTRODUCTION

To adequately understand a scientific experiment is in large part to understand science itself. The experiment contains all the elements that comprise the scientific enterprise: an intellectual tradition, a problem situation, instruments, human intellectual creativity, practical craft-skills, data, interpretations. Thus reflection on experimentation provides an avenue for the understanding of science. But this avenue has not always been followed, indeed it has been little travelled compared to the highways of empiricism and rationalism where the understanding of experiment has been little developed. The former seeking to understand science as an observational activity whereby a largely inert mind, or tabulae rasa, looks at and records the world in its, preferably, undisturbed state. The latter rationalist tradition down-plays observation, and stresses the role of the active mind in coming to know the world; in formulating satisfying, elegant and metaphysically consistent accounts of the working of the world. In particular this tradition emphasises the role of mathematics in scientific understanding, and the deep-seated mathematical intelligibility of nature.

In the ancient world Aristotle took the first path and Plato the second. Subsequent efforts at understanding science have largely followed in the footsteps of one or the other. From the Scientific Revolution onwards we can see Bacon, Locke, Hume, Whewell, Mill, Mach stressing the Aristotelian, empiricist, observationalist aspects of

science.¹ The logical positivists of the twentieth century, and even their most formidable opponent Karl Popper, continued this tradition of seeking to understand science as fundamentally an observational activity, albeit a sophisticated one. On the other hand Plato has not been without progeny. His is the tradition that has stressed the primacy of reason over observation in the understanding of the world. As Plato put it in the Theatatus "we see through the eye, not with the eye." Descartes and Leibnitz are in this tradition, as are (loosely) those post-positivist philosophers of science who stress the theory dependence of observation (Hanson, Kuhn, Laudan).

There has been a minority of philosophers who have sought to answer the perennial questions of scientific ontology, epistemology and methodology by focussing upon the scientific experiment. Here the key element of science is not the scientist as spectator (neither an observing nor contemplative one), but the scientist as a manipulator, intervenor and creator of circumstances in accord with reason. This experimental path to the understanding of science had of course to wait for experimentation to be developed as the method of science. This was Galileo's contribution.

The early champions of the Scientific Revolution failed to recognize the enormity of the change that Galileo and others had wrought upon science.² They failed to appreciate what Galileo himself claimed for his work: namely that it was a "new science of a very old subject."³

Immanuel Kant was the first to recognize the decisiveness of the Galilean break, and the epistemological consequences of the new mathematical-experimental science. In the Preface to the Second Edition of his Critique of Pure Reason he says

When Galileo caused balls, the weights of which he had himself previously determined, to roll down an

inclined plane . . . a light broke upon all students of nature. They learned that reason has insight only into that which it produces after a plan of its own, and that it must not allow itself to be kept, as it were, in nature's leading-strings, but must itself show the way with principles of judgement based upon fixed laws, constraining nature to give answers to questions of reason's own determining.⁴

Kant's central claim "that reason has insight only into that which it produces after a plan of its own" is the basis of the experimentalist understanding of science. It is at fundamental variance with the empiricism of Aristotle and later like-minded methodologists. By stressing activity, production and intervention it is at the same time at variance with the rationalism of Plato, and subsequent idealist and purely-mathematical methodologists. It did not suffice for science to merely create a plan, no matter how elegant and metaphysically agreeable: the plan had to be embodied in practice.

Karl Marx had a profound appreciation of Kant's insight. Thus his stress on practice as being epistemologically important; as mediating between our plans of the world and the world itself.⁵ Engels in commenting on the then debate between chemists concerning whether organic molecules could be synthesised from inorganic molecules says the answer lies in practice, in "experiment and industry." We prove the "correctness of our conception of a natural process by making it ourselves."⁶ John Dewey develops this experimentalist tradition in his stress on doing as a condition of knowledge, and his mistrust of 'pure' experience as a basis for understanding.⁷ The French historian and philosopher of science, Gaston Bachelard, cogently developed Kant's insight in publications prior to the second world war.⁸ (Unfortunately, they were little recognized by the dominant positivist school of philosophy in Europe and America. Much of what was so revolutionary in Thomas Kuhn's account of

science was already to be found in Bachelard's writings.) These writings were publicised mainly through their endorsement by the briefly-popular French Marxist philosopher Louis Althusser.⁹

This paper will illustrate some central tenets of the experimentalist comprehension of science by focusing upon features of Galileo's physics. In his epochal physics we can recognize the importance of reason, intellectual constructions, and most importantly mathematics; but we also see the importance of embodying these intellectual plans in the material world, of transforming circumstances so that nature can unambiguously answer questions we put.

Galileo's experiments are, in an Hegelian sense, the objectification of the scientific mind. The experiment is the vehicle whereby the scientific mind knows itself and transforms itself.

The picture of experiment to be elaborated has consequences for science pedagogy: how people learn to do science, and the skills and mental abilities involved in being scientific.

It may be that the account of experiment here illustrated has lessons for the constructivist account of epistemology,¹⁰ this because of the stress on material factors and craft skills in the testing and elaboration of knowledge -- these aspects being oft-overlooked by the rightful constructivist emphasis on intellectual concepts, models and creativity in the growth of knowledge.¹¹

II. GALILEO'S MATHEMATIZATION OF PHYSICS

The thesis can be well illustrated by following Galileo's on-going debate with Guidobaldo del Monte who was perhaps the greatest physicist of the sixteenth century and a mathematician of note.¹² He was an Aristotelian and a dogged empiricist. What was at stake was the legitimacy of adopting mathematics as the descriptive and analytic language of physics; and the bearing that observation and experience was to have on the mathematically expressed and proven laws of

physics. Here in embryo are the elements for the empiricist and the rationalist readings of Galileo. But as well, the debate with del Monte lays out the slowly developing unique contribution of Galileo to physics: namely separating the behavior of everyday objects, which is given in experience, from the properties of mathematized, ideal objects, which are not given in experience but are the subject matter of science. And once this separation of real and scientific objects is recognized, his reliance on carefully planned and executed experiments to vindicate the constructed properties of the scientific object.

Galileo's earliest work in mechanics was a student essay on the conditions of equilibrium of a balance (La Bilancetta 1586).¹³ The beginning of the divide between del Monte and Galileo is seen here, as is the beginning of Galileo's contribution to the mathematization of physics. Galileo represents the physical balance -- a plank, suspended by a rope, on which is placed weights -- by a straight line, divided at a point, with vertical forces superimposed. The real object in the world is depicted as a mathematical object. Given this depiction, Galileo proceeded to prove a new theorem about centers of gravity: if weights in arithmetical progression are equally spaced along the arm of a balance, their center of gravity divides the arm in the ratio of 2:1. This proof gained Galileo the esteem of prominent mathematicians in Italy and abroad, including del Monte.

Del Monte admired the mathematics but decried the physics. Clearly the depiction (familiar to all secondary school students) did violence to the facts. The physical balance plank was three dimensional, and of uneven composition; its fulcrum was an area, not a point; its weights inclined to the earth's center, they did not hang precisely parallel. Science, or physics, was to be about the behavior of everyday, real objects in the world. These were gross, messy, and imperfect. Only by falsifying the facts

could they be depicted mathematically. In a critical letter to Galileo he says:

These men are moreover, deceived when they undertake to investigate the balance in a purely mathematical way, its theory being actually mechanical; nor can they reason successfully without the true movement of the balance and without its weights, these being completely physical things, neglecting which they simply cannot arrive at the true cause of events that take place with regard to the balance.¹⁴

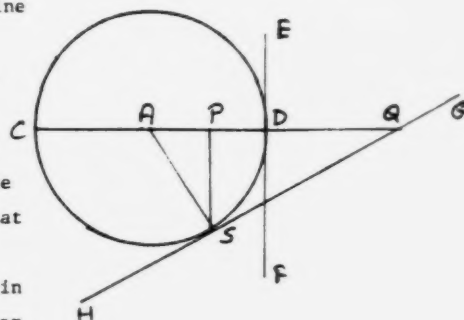
This treatment of the balance is the beginning of Galileo's separation of the theoretical or scientific object of knowledge, from the real or actual objects of the world. It is the beginning of the method of idealization in science. Such idealization being a prerequisite of mathematical representation.¹⁵ Yet what is distinctive of Galileo is his conviction that the truths proved for the scientific object are, in some way, applicable to the world: that a mathematical physics was possible. His account of experiment shows the way in which this applicability holds.

The major work of Galileo's Pisan period (1588-1592) was his De Motu.¹⁶ This is a brilliant Archimedean application of Euclidean argument to physical situations.¹⁷ Although brilliant, it was by no means novel;¹⁸ nor was it unflawed. For our purposes it is Galileo's treatment of the balance situation which is of importance. In one stroke -- by treating the balance arm as the diameter of a circle -- Galileo was able to unify the treatment of motions of a balance, of balls on an inclined plane and of free fall. All of which physics had previously treated separately, this largely because, following Aristotelian principles, the circumstances were all given differently to experience.

To give some feeling for Galileo's project let me reproduce his treatment of how the speed of free fall relates to the speed of descent of the same object on an inclined plane.

Galileo represents the circumstance geometrically, with the inclined plane at a tangent to the circle encompassing the balance arm. He addresses the problem this way:

But with how much greater force a body moves on EF than on GH will be made clear as follows, *viz.* by extending line AD beyond the circle to intersect line GH at point Q. Now since the body descends on line EF more readily than on GH in the same ratio as the body is heavier at point D than at point S, and since it is heavier at D than it is at S in proportion as line DA is longer than AP, it follows that the body will descend on line EF



more readily than on GH in proportion as line DA is longer than PA. Therefore speed on EF will bear to the speed on GH the same ratio as the line DA to PA. And as DA is to PA, so is QS to SP, *i.e.*, the length of the oblique descent to the length of the vertical drop... Consequently the same body will descend vertically with greater force than on an inclined plan in proportion as the length of the descent on the incline is greater than the vertical fall.¹⁹

In all of this there is no observation, no measurement, no recording of time, much less inductive generalization from numerous instances. It is a theoretical and conceptual effort. (Remember, time was then being measured by the weight of water flowing from a container.)

Galileo in an historically crucial amendment goes on to say:

But this proof must be understood on the assumption that there is no accidental resistance... We must assume that the plane is, so to speak, incorporeal

or, at least, that it is very carefully smoothed and perfectly hard ... And the moving body must be perfectly smooth, of a shape that does not resist motion... that weights suspended from a balance make right-angles with the balance.²⁰

Galileo has a law of moments which was conceptually arrived at; the result of what Alexandre Koyre called "thought experiments".²¹ Galileo recognizes that it is not true of actual balances. However his efforts are not purely idealistic, as he tries to enunciate the practical conditions under which the behavior of actual bodies would come to mirror that of his theoretical object. He has a recognition that scientific laws must be accompanied by a statement of caeteris paribus clauses. Del Monte points out that balances as we see them do not behave according to Galileo's law, and, further, his conditions of applicability of the law could never be realized. Consequently, according to del Monte, Galileo errs in believing his sophisticated mathematics can do double duty as physics. Physics is to be about this world, not an imaginary world.

The physical concepts -- force, heaviness, speed -- are not simple givens of experience or observation. They are intellectually constructed categories which are applied to the world. Further his diagrammatic representation with its points, lines and parallels -- is not given in experience but is the result of applying mathematics to the manifold of experience. Galileo knows that he is taking liberty with this experience. He shocks del Monte and other empiricist opponents by freely admitting that:

for the purpose of these proofs I am assuming as true the proposition that weights suspended from a balance make right angles with the balance -- a proposition that is false, since the weights, directed as they are to the center [of the earth and universe] are convergent.²²

Galileo's De Motu physics is still largely medieval in its problems and style. It is a youthful work written whilst

he was in his mid-twenties. His analytic concepts of force and heaviness were still conceptually confused. Indeed "heaviness" was to remain to the end an unresolved confusion -- he never freed himself from the Aristotelian idea that heaviness was a measure of a body's desire to return to its natural place, the center of the earth.²³

But Galileo in large measure divorced the concepts of science from the immediate everyday concepts of common sense so characteristic of Aristotelian science. He asks his audience to imagine that the wooden plane is "incorporeal"! Nature was addressed in mathematical terms, and her answers read by calibrated instruments many of which he himself crafted.²⁴ His mathematics and proto-theory enabled him to ask precise questions; questions that simply did not occur to those unfamiliar with mathematics or to those who eschewed its application to physics. Above all geometry gave Galileo the plan for the construction of experiments and the criteria for the interpretation of results.

Galileo's experimentalism consisted in constantly trying to perfect the actual balance in the direction of the ideal balance. The relevant variables for improvement were given by the mathematical constructions and the associated physical theory. They were itemised in the *caeteris paribus* clauses. As an experimenter, and a technician, Galileo strove to eliminate progressively more sources of error.²⁵ In other words, his experiment was meant to be theory objectified, the ideal realised.

In contrast to Aristotle, Hume, and modern inductivists, the Galilean theoretical starting point was not a real object, nor observations of such, rather it was an intellectually constructed, ideal object -- a scientific object -- whose salient properties were then imperfectly reproduced in experiments. And as they were imperfectly reproduced, so also were they imperfectly tested by experiment. Galileo was not a naive falsificationist. A constant refrain is:

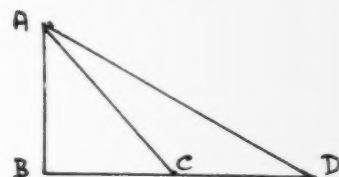
"I admit that the conclusions demonstrated in the abstract are altered in the concrete ... we must find and demonstrate conclusions abstracted from the impediments, in order to make use of them in practice under those conditions that experience will teach us."²⁶

That is, Galileo's laws do not apply to the behavior of bodies as we actually see them, only to behavior in rigorously constrained experimental circumstances, and even then only imperfectly. Conversely, one well constructed experiment tells us all we need to know: it does not have to be repeated, there is no need for inductive searches.

The account of experiment here developed is well illustrated in Galileo's treatment of the supposed isochronic motion of pendulums. I have dealt with the subject elsewhere.²⁷ Suffice here to say that del Monte knew from experience that actual pendulums were not isochronic, that the weight of the bob did effect the period of oscillation, and that whatever approaches to isochronism there were in long pendulums this was diminished as the pendulum length was shortened. In other words the law of isochronism, so central to Galileo's mature physics -- his proof of velocity varying with time and distance with time-squared -- was not true of actual pendulums. Such failure is a problem for Aristotelians and empiricists for whom the real and scientific objects are conflated, it is not a problem for Galileo.

Galileo's account of the pendulum also illustrates the powerful, unifying function that geometry played in his physics. By depicting the pendulum as having a length half that of the balance in his *De Motu* diagrams, he was able to conceptually unite free fall, balance, inclined plane and pendulum motions

He had shown that if velocity or free-fall varied with time, then in inclined-plane motion the terminal velocities of all planes of the same vertical height were the same.



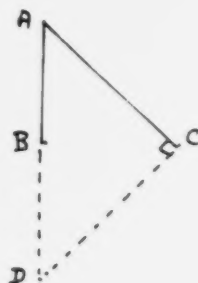
The velocity of a ball at B, C and D were equal.

Further the time of travel was proportional to the lengths traversed

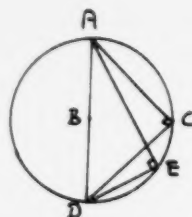
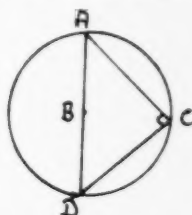
$$\frac{\text{time AC}}{\text{time AB}} = \frac{AC}{AB}$$

In an inspired and difficult move, he asked how far the object would fall in free-fall along AB whilst a similar object was traversing the incline AC.

This was given by constructing a right angle CD to intercept the extension of AB at D. Thus the same object travels AD in the time it travels AC.



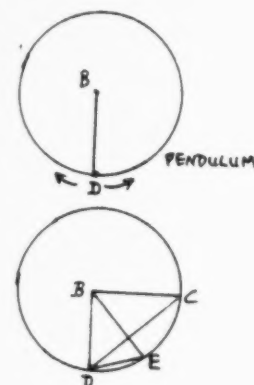
Because ACD was a right-angled triangle Galileo knew he could construct a circle around it on AD as diameter



But then all chords beginning at A will subtend a right angle when joined to D. Thus the time of travel along all chords in a circle for objects dropped and rolled from A is the same.

The pendulum circumstance is simply this diagram turned around, or looked at from another perspective.

Galileo has proved that the time of free travel along CD and ED (and any other chord to D) is the same. This is close to the law of isochronism. It need only be established that if time along the chords are equal, then so to is time along the corresponding arcs. This he does.



Having shown all this in the abstract²⁸ he was assured that a pendulum suspended at O, having a weightless string and a bob experiencing no air resistance, would swing through CD and ED (and any other smaller arc) in the same time. That actual pendulums did not do so, reflected not on his theory but on the construction of the pendulum.

III SOME PEDAGOGICAL LESSONS

The elaboration of Galileo's physics, and in particular his fashioning of the mathematical-experimental method, provides the occasion for canvassing numerous issues in science pedagogy: the role of historical case studies in science education; the cognitive presuppositions for understanding and embarking upon mathematical science; the appropriate role of observation and observation skills in science; should curricula reflect the logic of discovery in science or the logic of justification?; the influence of science in other areas of human endeavor; the place of

mathematics in science education. These issues, and others besides, can all in some way be illuminated by more careful appreciation of the Galilean achievement in physics.

I wish here to make only a limited claim, and given the tenor of my argument so far, perhaps a somewhat surprising one: let children be good Aristotelians before trying to develop them as modern scientists. As Hegel said of philosophy, so also of mathematical science: let it take wing at dusk.

It took the human race many thousands of years to get to the situation where Galileo's breakthrough in science was possible, it took the genius of Galileo a life-time to make it. One should not serve children the end product, rather let them learn by traversing some of the earlier ground. As weight-lifters say "no pain no gain."

Aristotle was a great observer of the heavens and the earth. To look at nature as it is and to ask questions about it, is an accomplishment for children. There is not much gain, and a great deal of loss, when children are taught a model of the solar system without ever looking at the sky, without being able to recognize a planet when it passes above their heads, without having to figure out for themselves why the earth could be spinning and moving through space yet we not fly off it, and why balls dropped, from towers don't fall miles away.

Galileo's mathematisation of physics required enormous intellectual and conceptual effort. So does the understanding of his achievement. There is now a great deal of evidence from cognitive-developmental studies that shows that children, and indeed university students, do not have the intellectual resources to master such material.²⁹ Without it, their repetition of mathematical formulae and conceptual definitions becomes mere parrot-talk. They may as well learn a shaman's incantations.

The great bulk of science teaching results in children (and university students) falling between two stools. They don't have the interest in, and appreciation of, nature that

Aristotle with his purposive metaphysics and his ceaseless observation and cataloguing of the plant and animal worlds developed.³⁰ Nor do they develop the sense of wonder and excitement that Galileo felt when he realized that when material specifics were abstracted, the world was fundamentally mathematical.³¹ Aristotelian-like nature study gives way too soon to Galilean-like mathematical science.

If science education is done slowly, reflectively, and in keeping with the interests and capacities of children, then gradually the idea of an idealised, experimental-mathematical methodology can be introduced. The common-experiment can be the occasion for stressing the conceptual, creative dimension of science; the practical craft-skill aspects of science; the instrumental-dependence of measurement; the central tension between reason and observation in the development of science.

The fundamental pedagogical and epistemological stumbling block is that scientific laws do not describe the behaviour of actual bodies.³² The gas laws, inheritance laws, Newton's laws, Piagetian stages etc. -- all of these describe the behaviour of ideal bodies, they are abstractions from the evidence of experience. The laws are true only when a considerable number of disturbing factors (itemised in the *caeteris paribus* clauses) are eliminated. This can seldom be done (for the law of inertia, by definition it is impossible to eliminate the secondary factors). The art of experimentation is to progressively try to do so.

On the positive side, this Galilean idealisation (the defining characteristic of modern, non-Aristotelian science) is a feature of all cognition and language use. The terms "democracy", "gross national product", "flower", "triangle", "tree", "good person" etc. are all labels that apply only imperfectly to any actual, concrete, state of affairs. In using language we all the time pick out essential features of a situation and ignore others: we abstract. Consider how we use the word "science" itself. Abstraction is a feature of all cognition. If this can be pointed out by everyday

examples, then students can be progressively prepared for the abstractions of mathematical physics, and progressively weaned from the constraining influence of empiricism.

NOTES

¹Aristotle's scientific method is a complex matter. For our purposes it is his constant stress on beginning with observation which is important. In the Posterior Analytics, Bk. II, Ch. 13, he says

To resume our account of the right method of investigation: We must start by observing a set of similar -- i.e. specifically identical-individuals, and consider what element they have in common.

Science here begins with the observation of actual real objects, in their natural state, acting as they do standardly. Further the means of observation is the unassisted, and uninterfered with, eye. The mind, or nous, then finds the common essence or basic principles (archai) of the given subject matter.

²See Jurgen Mittelstrass, "The Galilean Revolution: the Historical Fate of a Methodological Insight" Studies in the History and Philosophy of Science (1972), 2:297-328.

Also, Alan Chalmers, "A Non-Empiricist Account of Experiment, Methodology and Science, 1984, 17.

³Henry Crew and Alfonso de Salvio (trans.) A Discourse Concerning Two New Sciences (New York: Dover, 1914), p. 242. This reproduces his conviction of forty years earlier expressed in a letter to Belisario Vinta (1610) that he discovered:

an entirely new science in which no one else ancient or modern has discovered any of the most remarkable laws which I demonstrate to exist in both natural and violent movement.

Stillman Drake, Discoveries and Opinions of Galileo (New

York: Doubleday, 1957.

⁴Kemp-Smith translation, B xiii-xiv.

⁵See W. A. Suchting, Marx and Philosophy (London: Macmillan, 1986).

⁶K. Marx E. & F. Engels, Selected Works (Moscow: Progress Publishers) Vol. III, p. 347.

⁷See John Dewey, Essays in Experimental Logic (Chicago: University of Chicago Press, 1916).

⁸Caston Bachelard, The New Scientific Spirit (Boston: Beacon Press, 1984); The Philosophy of No (New York: Orion Press, 1968).

⁹Louis Althusser and Etienne Balibar, Reading Capital (London: New Left Books, 1970).

¹⁰Usually associated with the works of Jean Piaget. See elaboration in Ernst von Glasersfeld, "An Introduction to Radical Constructivism", in P. Watzlowich (ed.), The Invented Reality (New York: Norton, 1984).

¹¹A useful Marxist-inspired commentary on Piaget is Marx Wartofsky, "Piaget's Genetic Epistemology and the Marxist Theory of Knowledge", Revue Internationale de Philosophie (1982) pp. 470-508.

¹²For translations of his mechanics, and claims of his preeminence in 16th century mechanics, see S. Drake and I. E. Drabkin (eds.) Mechanics in Sixteenth-Century Italy (Madison: University of Wisconsin Press, 1960).

¹³Translated in L. Fermi and G. Bernardini, Galileo and the Scientific Revolution (New York, 1961).

¹⁴Drake and I. E. Drabkin (eds.) Mechanics in Sixteenth-Century Italy, p. 278-79.

¹⁵Edmund Husserl in 1901 introduced the concept of idealization to characterize the distinctiveness of Galilean physics. See his Logical Investigations trans. G. N. Findlay (New York: Humanities Press, 1970), pp. 450-1. The

philosophical import of the notion was developed in his The Crisis of European Sciences and Transcendental Phenomenology trans. David Carr (Evanston: Northwestern University Press, 1970). For these references I am indebted to James Garrison of Virginia Polytechnic and State University. See his "Husserl, Galileo and the Processes of Idealization," Synthese (1986), 66:329-36.

Further development of the notion of idealization in science occurs with the Marxist Poznan group. See particularly L. Nowak The Structure of Idealization (Boston: Reidel, 1980). And essays in W. Krajewski (ed.) Polish Essays in the Philosophy of the Natural Sciences (Boston: Reidel, 1982).

¹⁶Translated in I. E. Drabkin and S. Drake Galileo Galilei on Motion and On Mechanics. De Motu was never published by Galileo. It existed as a preliminary Dialogue and then a complete, twice-revised, twenty-three chapter Essay. See Raymond Fredette, "Galileo's De Motu Antiquiora" Physis (1972), 14.

¹⁷For Galileo, Archimedes was "superhuman" and he never mentioned his name "without a feeling of awe" (De Motu, p. 67).

¹⁸E. J. Dijksterhuis regards the work as "closely akin to the Paris Terminists" -- The Mechanization of the World Picture (Oxford: Oxford University Press, 1961), p. 334. This view is shared by Dudley Shapere -- Galileo: A Philosophical Study (Chicago: University Chicago Press, 1974), p. 78.

¹⁹De Motu p. 64-5.

²⁰Ibid.

²¹Alexandre Koyre Metaphysics and Measurement (Cambridge Mass.: Harvard University Press, 1968); Galileo Studies (Hassocks: Harvester Press, 1976).

²²De Motu p. 67.

²³Richard S. Westfall, "The Problem of Force in Galileo's Physics," in C. L. Golino (ed.) Galileo Reappraised (Berkeley: University of California Press, 1966).

²⁴Northern Italy at the end of the sixteenth century was the centre of a major transformation in craft skills and technical innovation. Galileo contributed to this. He was a pioneer in the theory and construction of the most important new scientific instruments of the time: balances, proportional compasses, clock mechanisms, thermoscopes, microscopes, and, of course, his world-view-changing telescope. See Silvio A. Bedini, "Galileo and Scientific Instrumentation", in W. A. Wallace (ed.) Reinterpreting Galileo (Washington: Catholic University Press, 1986).

These instruments, as with all scientific instruments, made sense only in the light of the theory by which they were constructed. Thus Bachelard's comment that "the instrument of physics is a realized, concretized theory, rational in essence" (The Philosophy of No, p. 21).

²⁵On these aspects of Galileo's methodology see Noretta Koertge, "Galileo and the Problem of Accidents," Journal of the History of Ideas (1977), 38: 389-409. Also Ernan McMullin, "Galilean Idealization", Studies in the History and Philosophy of Science (1985), 16: 347-73.

²⁶Stillman Drake (trans.), Two New Sciences (Madison: University of Wisconsin Press, 1974), p. 223.

²⁷"Galileo's Pendulum and the Objects of Science", Philosophy of Education (Proceedings of the American Philosophy of Education Society), 1987.

²⁸The process whereby Galileo arrived at these conclusions was not as clear-cut as here indicated. He first thought that velocity of fall varied as density, and he also thought it varied with distance. These views were only slowly rectified. See Ronald Naylor, "Galileo's Theory of Motion: Processes of Conceptual Change in the Period 1604-10", Annals of Science (1977), 34: 365-92.

²⁹E. L. Chiappetta, "A Review of Piagetian Studies Relevant to Science Instruction at the Secondary and College Level", Science Education (1976), 60: (2).

³⁰A sense of the Aristotelian appreciation of nature is given in his Parts of Animals Bk. 1 ch. 5.

Having already treated of the celestial world...

... we proceed to treat of animals, without omitting, to the best of our ability, any member of the kingdom, however ignorable. . . . for each and all will reveal to us something natural and something beautiful.

³¹Thus Galileo's famous metaphor of the Book of Nature being written in mathematical symbols and his claim (following Plato) that a person ignorant of mathematics cannot hope to understand nature; that is, be a scientist.

³²A point developed at length by Nancy Cartwright in her How the Laws of Physics Lie (Oxford: Clarendon Press, 1983).

COMMON SENSE KNOWLEDGE VERSUS SCIENTIFIC KNOWLEDGE:
THE CASE OF PRESSURE, WEIGHT AND GRAVITY

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Introduction

The majority of researches on alternative frameworks and common sense knowledge points out the analogies that can be elicited between the common way and the scientific way of giving meaning to reality. At the same time, however, also differences are mentioned and the need for a "conceptual change" in scientific learning is stressed.

The aim of this work is to recognize both analogies and differences, and to discuss differences mainly, between common sense knowledge and scientific knowledge, firstly from a general point of view, secondly by reporting the experience gained in a specific context.

Scientific knowledge and common sense knowledge: some general considerations

In 1938, Bachelard pointed out that, both from the historical and the individual point of view, scientific knowledge is built up through a progressive differentiation from common sense and therefore by overcoming the "epistemological obstacles".

"Une expérience scientifique est alors une expérience qui contredit l'expérience commune....elle manque de cette perspective d'erreurs rectifiées qui caractérise la pensée scientifique."
(Bachelard, 1938)

Overcoming does not mean, in Bachelard's rationale, to remove obstacles but to include them in an "epistemological profile" (Bachelard, 1940) which is typical both of the specific concept and of individual thinking.

What is changing, in the different parts of the profile, are the experiences and the "theories" used to give meaning to the experiences. In general, the differences in "game rules" used in the different stages of the profile, which generates the obstacles, remains implicit. But what are the rules of common sense knowledge? Carlo Ginzburg, an Italian historian, proposed for human sciences a "circumstantial paradigm" (1979), versus the "Galileian paradigm", typical of natural sciences. In a "circumstantial paradigm" what matters are the differences, and not the analogies. The same happens in life, and in common sense knowledge. Small differences, small "signs", enable Sherlock Holmes to solve the enigma; or Frate Guglielmo in Umberto Eco's "The Name of the Rose" to describe the Abbott's horse without having seen it; or the wise farmer to forecast weather.

On the contrary, natural sciences follow the Galileian paradigm and aim at simplicity, coherence and generalization. The results they get, with these "epistemological commitments" (Hewson, 1985) are fundamental but they concern only relatively small portions of reality. As reality is a complex matter, to apply the rules of science to know it means to simplify it. It is like intersecting a complex n-dimensional solid with a plane: what we obtain is only a very "special representation" of the solid. If we use different planes, every section corresponds to a different discipline or to a different part of a discipline, a different level of reality, with its own "facts", "theories", and "rules".

Common sense knowledge itself corresponds to a level of reality. But the surface representing it is not a plane but a complex surface: nearer to reality for some aspects, but more idiosyncratic and difficult to define than scientific knowledge.

In order to pass from a level of reality to another, and then from common sense knowledge to scientific knowledge, a change of the system of rules is necessary.

Following Russel and Whitehead, this kind of change belongs to a different logical type compared with a change which takes place within the rules. The latter is called by Watzlawick and others (1975) a "change-1", the former a "change-2". Watzlawick suggests the following example of a "change-2": nine points, arranged as in the figure, have to be connected with four consecutive straight lines.



figure 1

As Watzlawick pointed out, the solution can be found only by considering the problem hypotheses and rules, including the "tacit" and "implicit" rules and taking a decision about their pertinence. In the previous example, the rule:

"the four straight lines have to be drawn inside the square defined by the nine points"

is a very common "tacit" rule, which is not set by the problem itself, and could become an obstacle in finding a solution.

Change-2 is a kind of change which enables us to pass from a system of rules to another, from a level of reality to another.

According to Bateson and Watzlawick, learning is linked to these two different kinds of change. Bateson (1972) recognizes different kinds of learning: learning-1 that corresponds to rote-learning; learning-2 that corresponds to

meaningful learning but without any meta-cognition of the game-rules; and learning-3, where the meaningful learning goes together with the awareness of both game-rules and the particular point of view generating such rules. In order to pass from one kind of learning to the other, a change-2 is required.

In this perspective, looking at common science knowledge (a general system of rules) from the point of view of science (a different and more defined system of rules), aiming at understanding the former, will be an unsuccessful strategy. Instead, looking separately at both levels of reality enables us to perceive different rules and schemata. Asking a pupil's opinion about a single fact, or a single isolated concept, like pressure or gravity for instance, could hide the complex network, the conceptual map which lies behind, or around, every concept. In fact, differences can be found not only in specific concepts, or in broader conceptions, but in the conceptual networks, in different relationships between different facts established by different theories.

Design of the research and first general results

With this rationale in mind, the research I carried out in the course of three years foresaw a qualitative analysis of different conceptual maps in scientific and in common sense knowledge, and a quantitative analysis of these differences within a group of students from secondary school. On the qualitative side, for every concept or group of concepts, taken into account, I compared a "scientific" conceptual map with a "common sense knowledge" map. Obviously, these maps are not "individual" maps but general maps derived the one from the history of science and current text book, and the other from previous researches using individual or group interviews.

On the quantitative side, the research aimed at comparing the scientific knowledge acquired after a two or three years physics course, in different types of secondary

schools, with the knowledge pupils have before physics teaching.

Five physics "topics" were explored: three of them linked to the curricula - "Inertia", "Force", "Electric Circuits" - and two derived from common sense problems - "Light and vision", "Pressure, Weight and Gravity".

On these five topics, and their respective conceptual maps, five questionnaires were built in two different forms suitable to be administered before and after the physics course.

The questionnaires consisted of free answer questions, mostly concerning the meaning students give to basic words used, and multiple choice questions, asking also for an explanation of the answers.

The whole sample consisted of 600 secondary school students, aged from 14 to 18 years, and coming from three types of secondary school (humanistic, scientific and technical).

Since not all the students were asked to answer all the questionnaires, we have different samples for the five different topics. Besides, the pre-instructional and the post-instructional forms are designed to be very similar in order to allow a comparison between the answers.

Table 1 shows the results obtained for the three topics Inertia (I), Force (F) and Pressure, Weight and Gravity (P) (1 refers to the pre-instructional form, 2 refers to the post-instructional form, no number refers to common items).

Every scientific answer - supported by a correct explanation - scored 1 point. The value of mean $\bar{x}$, and the standard deviation σ , compared with the number of items, show how difficult it is to master a coherent and meaningful scientific view of reality, even after a physics course.

Table 1 - Results of I, F and P questionnaires

	I1	I2	I	F1	F2	F	P1	P2	P
Number of students	174	195	369	282	263	544	229	289	518
Number of items	12	28	12	20	23	20	20	19	18
Mean	3.01	11.36	4.05	6.34	9.44	7.45	5.32	6.80	5.62
Standard deviation	1.85	4.44	2.36	2.41	3.72	3.11	2.50	3.60	3.29
Cronbach α	.478	.767	.642	.407	.719	.637	.530	.766	.741

In Table 2 the results of the Analysis of Variance, calculated for different variables gathered by means of a background questionnaire, are shown. It is easy to observe that differences in sex and time spent on the task are more significant in Inertia and Force questionnaires than in the Pressure questionnaire.

On the contrary, father instruction and mother instruction are more significant in the Pressure and Gravity questionnaire. The same result occurs in the Light questionnaire. It therefore seems that performances in questionnaires more linked to "common sense knowledge" are less dependent on sex and time spent in task, and more dependent on the family's level of culture. Specific teaching improves this performance, as it emerges from the high

significance of the variance for "year of course", but it will not cancel this preexistent difference.

Table 2 - Analysis of Variance

Background Variables	I	F	P
Sex	.01	.00001	.05
Year of course	.00001	.00001	.00001
Father's instruction	.08	.24	.01
Mother's instruction	.15	.26	.04
Further education choice	.06	.04	.02
Interest on Physics	.02	.0004	.04
Attitude toward science	.14	.02	.01
Time spent	.00001	.0006	.13

In the following I will present in some detail the questionnaire on Pressure, Weight and Gravity, and some qualitative and quantitative results.

Pressure, Weight and Gravity: common sense knowledge

Researches carried out in Italy from 1981 (Dupre' et al., 1981) (Vicentini, 1982) pointed out that both adults and children perceive the concepts of force of gravity and weight as separate. Furthermore, people often assume that gravity and/or weight have to do with the presence of the air and/or atmospheric pressure.

Other researches on gravity (Gunstone and White, 1981) and on forces (Watts and Zylbersztain, 1981) confirm this distinction between gravity and weight, together with a possible connection with the presence of air. On the other end, researches on pressure and on atmospheric pressure (Engel and Driver, 1981) highlight other kinds of difficulties related to the concept of vacuum.

The results of these researches enable to infer a "common sense" conceptual map like as shown in figure 2.

In this map different possible networks can be represented: weight may, or may not, be considered only as a characteristic property of bodies, depending on the quality and the quantity of matter, and therefore be confused with the concept of mass. But weight may be, from another common sense point of view, correctly defined as a force, responsible for the fall of bodies, directed downwards, but having nothing to do with gravity.

Gravity, in its turn, is not a common word: it is used at school and sometimes on TV but with no clear meaning. "Grave", in Galileo's language, is a body that can fall; gravity is the falling down property, and in this meaning air and fire, that don't fall, are not "gravity liable". They do not fall and "they are without sensible weight".

Pressure too is not a very common word, and is used in very different situations: in weather forecasting, to indicate the "pressure cooker", for water pressure in pipelines, etc. In any case, what is in general clear is the presence of something that "presses" and that involves, in common sense knowledge, a "force". For the atmospheric pressure, this force is seen as directed only downwards.

"Vacuum" and "empty space" are concepts corresponding in Italian (just as in Greek and Latin) to a single word: "vuoto". This "vuoto" may therefore be, in common sense knowledge, an "empty space" filled with air, or a real and complete "vacuum". In the first meaning the word is used in everyday life, while in the second one the word often describes the interplanetary space, where the concept of "no air" is, implicitly or explicitly, linked with "no gravity".

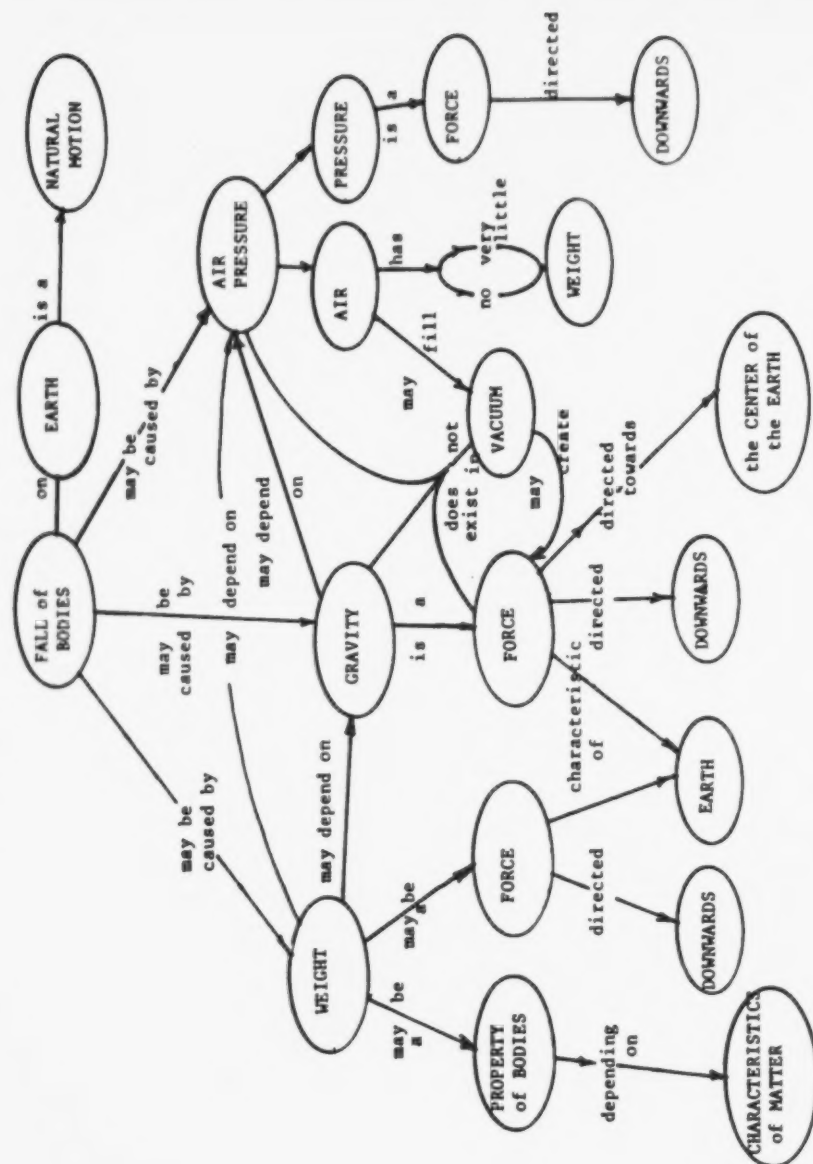


figure 2 - Common Sense Conceptual Map

Pressure, Weight and Gravity: scientific knowledge

According to the present scientific point of view, many of the links supposed by common sense are seen as absurd: the behaviour of gases, and then air and air pressure, "belong to a different physics chapter" than weight and gravity. Pressure is often introduced in textbooks like F/S among mechanics topics and by the fact that textbooks often deal only a little with hydrodynamic and, what is more serious, with thermodynamics, the fundamental role of pressure in fluids is in general disregarded. Gravity is important to explain the presence and the density of Earth and planets atmosphere, but in physics textbooks this kind of links are considered as irrelevant.

The map in figure 3 will show the textbooks principal network (solid lines) and some other possible scientific links (dotted lines).

The present scientific knowledge is however the result of historical development: in the past, opinions about movement, falling bodies and vacuum were very different from today, and in some cases very similar to common sense knowledge. This is the case of the "falling down of heavy bodies" - "a natural notion" that needs not to be explained according to Aristotele and to many pupils- the lack of weight for air and gases, or, if vacuum does exist, the absence in vacuum of both air and force of gravity.

It is important to be aware that, in the past, physics, like astronomy, was a cosmological science, and its principal aim was to understand the structure of the universe. In this view vacuum could be considered as impossible because in it

"the up will not differ from the down... and then no displacement will exist anywhere" (Aristotele, Physics, IV).

When, in Galileo's times, vacuum became to be conceivable, gravity, and then the "falling" feature, was

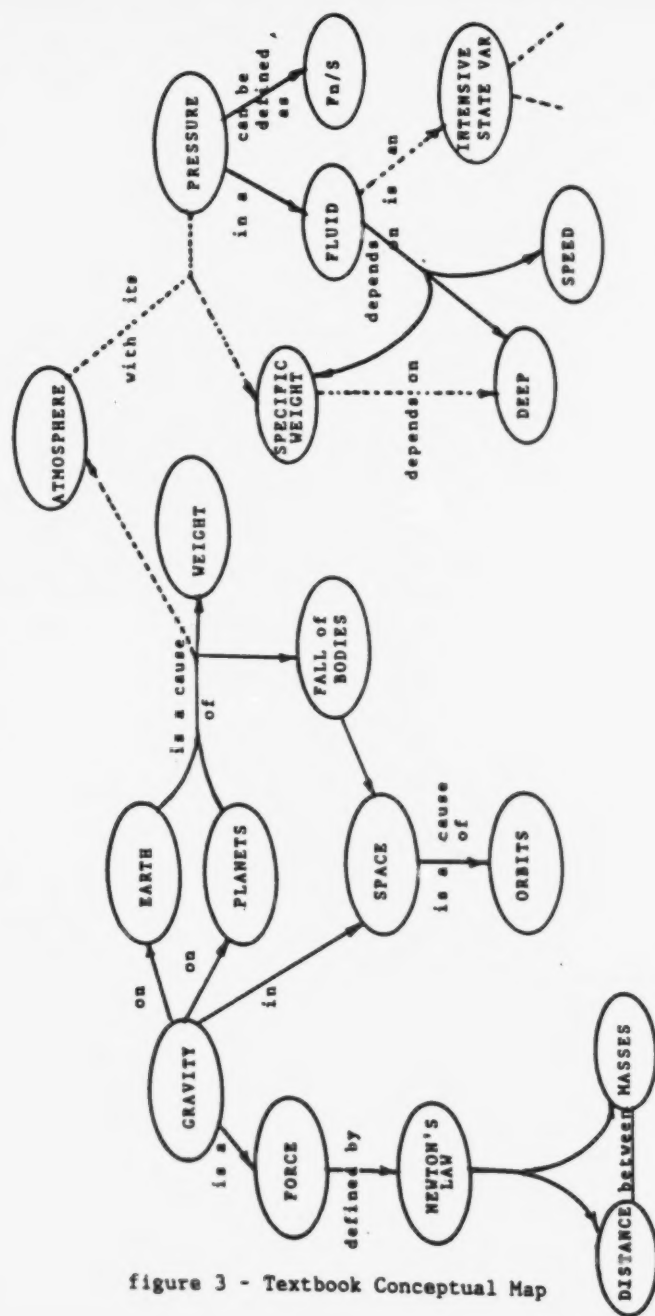


figure 3 - Textbook Conceptual Map

considered as a, not separable, characteristic of bodies. For this reason the Galileian Inertia principle was formulated only for bodies moving on a "horizontal plane", where falling is prevented, and when extended to the Universe, it became a "circular" Inertia. Only after the Gilbert and Gassendi hypothesis of an analogy between magnetic and gravitational forces (analogy often proposed in primary school textbooks), gravity can be considered like an external force, and the inertial motion can be conceived as a rectilinear one. Nevertheless Gassendi himself, conjecturing about the existence of vacuum, remarked that no motion and no forces would be possible in it, because a body

"with no contact with Earth, and with no other thing in the world, would behave as if the world, the Earth and its center, were not existing at all..." (Gassendi, De Motu)

In this case, the problem of conceiving gravity in a vacuum is clearly related to the problem of conceiving a "distance action" instead of a "contact action".

In conclusion the past scientific view considered gravity as an effect (and not a cause) of weight of bodies, and linked the absence of air to the absence of forces and movements, like today's common sense views.

The questionnaire: the meaning of the concepts

By comparing the two maps, the common sense map and the scientific one, it is easy to notice a lot of differences: some arise in the meaning of specific concepts, others are differences in relationships between concepts.

On the basis of these differences, a questionnaire was built, using questions derived from other researches, when applicable to the problem. Using free and multiple choice answers, together with explanations the pupils gave, it was possible to check the hypothetical common sense map previously drawn, to find other not foreseen relationships,

and have an idea of the distribution of different mental representations in the sample examined.

At the beginning of the questionnaire four "free questions" were given:

"what is pressure for you",

"what is gravity"

"what do you mean by "weight"".

"what do you mean by "create a vacuum"

Analysing the different answers, one may assign some percentages to the different possibilities foreseen in the map drawn in figure 2.

Therefore, for the 59% of pupils before and the 49% after a physics course, pressure is simply a force; the F/S definition is shared by only the 7% before and by the 38% after the course, but references to the fluids and to the atmosphere decrease with schooling.

Many answers (20% in both cases) show a deep confusion between weight and mass. For 25%, the weight of bodies is a force with no relations, or with erroneous relations, with gravity, and only 44% after the physics course recognizes the weight as an effect of the gravity.

For the 40% of pupils before teaching and the 24% after, gravity is a "force" the important features of which are:

- 1) either "to keep the objects steady on the ground, without floating, as it happens on other planets", being directed "downwards";
- 2) or "to keep the objects floating" or "to prevent falling, for example to prevent the falling of the Moon on the Earth".

This second meaning has a quite reliable source, as a girl wrote in her explanation: "I saw it on the TV during the Shuttle launch... With the engines out, the rocket was kept in orbit by gravity".

The 36% of pupils before, and the 42% after teaching, think that the force of gravity is "typical of the Earth" and

often directed "downwards". Only the 21% after teaching extend the law of gravity to other planets or to any couple of masses.

Finally, to "create a vacuum", a sentence that in Italian has an "everyday" sound and meaning, was explained by the 14% of pupils before teaching as "to create an empty space", empty of objects but filled with air. The 65% interpret it just as "to take away everything", air included. But many of them, as it has been possible to establish looking at other answers in the questionnaire, by "everything" mean also "forces and gravity". Moreover, some of these students (with a percentage increasing with schooling, 11% before and 20% after) declare this belief explicitly:

"to take air out of a given space means that the objects in this space will float".

The conclusions of the analysis of this first part of the questionnaire are:

- scientific definitions are difficult to remember, and to master. Only a percentage ranging from 20% before to 40% after a physics course is able to give a meaningful explanation of the four concepts proposed;
- definitions before teaching are rich, in terms of imagination and references to everyday situations; after teaching, they become poor, not only as to variety, that would be obvious, but also as to relationships pupils are able to establish between these definitions and examples from everyday life.

Pressure will be a good example: the school teaching "selects" between different spontaneous definitions the one: $P = F/S$, and attached it to a few examples like a brick on the sand, or the hydraulic press. Other life examples, like "the pressure of water in a tube" or "the pressure of air in a balloon", with their important scientific features, remain

neglected, because they don't easily fit with the F/S definition.

The questionnaire: main factors and results

The two questionnaires on Pressure, Weight and Gravity consisted respectively of 20 and 19 items, 18 of which in common.

A Factor Analysis confirms the importance of different conceptual factors, some of them related to single concepts but others, more significant, concerning the relationships pupils establish between concepts.

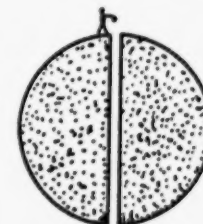
The analysis pointed out the importance of ideas students have about air. Even after teaching, the majority of students think of the air contained in the classroom as if it were either without weight, or as light as a "feather". In these cases, weight and pressure are different things: "air has no weight, it has only pressure" writes a student.

Pressure itself is not well understood even by students that in the free questions gave the correct, conventional answer: F/S. In fact, when they come to more specific questions, they think of pressure as a force directed only downwards and acting on an horizontal surface. For the 36%, both before and after teaching, a balloon kept at the bottom of a deep swimming pool is "flattened" by the water pressure. If the pressure will become too high, the balloon will "burst" for the 26% of students. Also when pressure is clearly not directed downward, as when the balloon bursts in the air, for more than 40% the pressure that causes the burst is external.

The most important factor of the questionnaire, that explains the 15% of variance, is given from the group of items about "the hole in the Earth". The question was the same proposed by Nussbaum and Novak in 1976:

Interviewer to pupil: Suppose that

someone dug a hole all the way through the earth and dropped a rock into it.



On these pictures below, of a make believe earth, four different children (a,b,c, and d) drew a line showing the way a rock would move as it falls. Which drawing best shows what would really happen to the rock?....Why do you think so?

figure 4

Differences were introduced which had already been checked and discussed in researches made at the University of Rome (Dupre' et al. 1981):

- only one of the paths proposed to the students ends in space;
- two other paths, which end before or beyond the center, were proposed;
- two other items were proposed where the hole does not pass through the center and is drawn "inclined" or "horizontal" with respect to the sheet. For these two latter items the students have to draw the path of the rock themselves.

The percentages of answers change substantially when the position of the hole changes with respect to the sheet.

The results are shown in the following Table:

Categories of responses	Vert.		Inclin.		Horiz.	
	P1	P2	P1	P2	P1	P2
	%		%		%	
Goes out the hole or stands (flat Earth)	17	8	25	10	49	35
Goes through the Earth (geographically spheric Earth)	24	11	40	35	14	8
Stops in the Center (physically spheric Earth)	50	59	31	40	36	40
Oscillates (scientific scheme)	1	18	1	15	.5	16

Table 3 - The hole in the Earth

A "flat Earth scheme", where the force is only downward, becomes more frequent when the hole is drawn horizontally. Even when the hole is only inclined, the fact that at the same time it does not go through the center enables some of the students to formulate a difference between gravity and weight:

"gravity attracts the rock to the center, whereas weight pulls it. Since the hole does not go through the center, gravity will not act".

A "geographically spheric Earth scheme" is particularly attractive when the hole is inclined. In this scheme, bodies fall toward the center only if they are outside the Earth surface. Inside the hole the bodies fall down to the other side. Often, in this scheme, the cause of gravity is ascribed to air pressure, that presses from outside towards the Earth surface.

A "physically spheric Earth" scheme is the most popular, but not very consistent. About 20% of students change their ideas when the position of the hole changes. 30% before teaching and 40% after remain consistent in all three items. It is important to point out that mastery of the latter scheme does not imply mastery of the concept of gravity. The

cause of the falling toward the center may be, in fact, the weight or the air pressure or, as a student wrote "the center is the natural place for heavy bodies".

A "scientific scheme", where inertia is taken into account, seems to be very consistent but it is understood only by very few students, even after the physics course.

It has to be noticed that school teaching sometimes leads to confusion: pictures in textbooks, maps and the Earth globe support a scheme where "high" and "down", "vertical" and "horizontal" are absolute, and not relative, concepts. A very good student answered in this way to the question "Why does the Moon not fall on the Earth?":

"The Moon goes round the Earth on a horizontal plane, so if it fell down, it would fall along a vertical line and would not impact on the Earth, but would be lost in space".

Another very significant group of items considered what will happen in the absence of air. The examples proposed were:

- an astronaut and a satellite moving around the Earth;
- an astronaut on the Moon leaving a wrench (Watts and Zylbersztain, 1981);
- an object on a scale inside a jar from which air is taken out with a vacuum pump (Ruggiero et al., 1985).

The questions were: "what will happen with gravity (or with falling or with weight) in the following situations?"

The answers show that about 50% of students, also after a physics course, think that "no air" implies "no gravity", and some of them add that air pressure is responsible for gravity. The percentage decreases with schooling for what regards the relationship "no air - no weight": even after teaching, the 30% of students think that in a vacuum there will be no sensible weight.

The falling down of objects is even less related to the

presence of the air. Only 30% before and 20% after teaching think that without air objects will float in the space.

Comparing the percentages, it is obvious that for about the 30% of students the falling of bodies is not caused by gravity or by any other force, but is a kind of "natural motion".

For more than 20% of students, weight and gravity are not related concepts, and in the absence of air it will be possible to have either.

Conclusions

The common sense conceptual map, sketched in figure 2, has been verified and in some parts completed by the results of the questionnaire. Clearly there emerges the complexity and the difficulty in defining conceptual hierarchies at the common sense level in comparison with the scientific level. The common sense map represent in this case an attempt to give meaning to many concepts, most of which are known only through the informations gathered from school and mass media.

In fact, apart from the basic experience of the falling of bodies and the carrying of weights, Earth sphericity, air weight, atmospheric pressure or gravity, are all words slightly related to experience. These words are interpreted and linked together in order to find a meaning, following some basic rules:

- similar concepts are used in a similar way in language (then weight is similar to mass, empty space to vacuum - at least in Italian - and so on), but at the same time different words must have some differences in meaning (then weight has to be different from the force of gravity);
- new concepts have to fit with old experiences: then "up" and "down", "top" and "bottom" have a clear and absolute meaning, and it is difficult to pass from this "cartesian frame of reference" to a "spherical" one;

- new concepts have to fit in old theories, even if they are "tacit", not explicit, common sense theories. The "no air-no gravity" fits with the need of "contact forces", and "gravity is a force that maintain things floating in orbit" fits with the need of a force "to hold a body".

In this way, also scientific information are interpreted from a common sense point of view, and supports the alternative frameworks.

The family level of culture has, in the case of Pressure, Weight and Gravity, a special importance because parents, more than teachers, can help the child in giving meaning and create networks for the information he receives from every day life.

As it is well known, very often teachers are not aware of the lot of information, and therefore meaningful concepts and networks, children already have when they come into the classroom. In the present research, teachers were asked to anticipate the results their students would achieve in terms of a three points scale of difficulty:

- 1, low difficulty (more than 70% of correct, scientific, answers);
- 2, average difficulty (between 30% and 70% of scientific answers);
- 3, high difficulty (less than 30% of scientific answers).

The results of this prevision from the Pressure and Gravity questionnaire are reported in the Table 4, for the 12 classes that answered the questionnaire after the teaching.

The (+) and (-) signs mean that the expected difficulty was wrong, that is it was higher (+), or lower (-) than the real performance.

The high number of plus and minus (more than 50% of teachers previsions) means that teachers previsions are substantially different from students performances. Moreover, for some items and some teachers, the versus of the difference is highly significant, as assessed by the statistical "sign test".

Table 4 - Expected difficulty and actual performance

Class	C1A SE	T3A 2L	T4A 2I	T4A 2G	T3A 2M	S1A 4D	S2A 5B	C3A 5E	T4C 3G	T4B 3B	C2A 5A	C2A 5E	p=
01	2	2	2	2	2	1	1	2 ⁺	1	1	2 ⁺	1	
02	3 ⁺	2	2	2	2	2	1	2	2	1	1	2	.02
03	3 ⁺	2	2	2	2	2	2 ⁺	1	2	1	1	2 ⁺	
04	2	2	3	3	2	3	2	2	3	2	2	3	.05
05	3	3	2	2	2	2	1	3	2	3	1	1	.004
06	2	2	2	2	2	2	1	1	2	2	1	2	.002
07	3 ⁺	2	2	2	2	3 ⁺	3 ⁺	2	2	3 ⁺	2	1	
08	2	2	2	2	2	3 ⁺	1	1	3	3 ⁺	1	3 ⁺	
09	2	3	2	2	2	1	1	1	2	2	1	2	.004
10	2 ⁺	3 ⁺	3 ⁺	3 ⁺	2	3 ⁺	2 ⁺	2	2	2	1	3 ⁺	
11	2 ⁺	2	2	2	2	1	1	1	1	2 ⁺	1	2 ⁺	
12	2	3	3	3 ⁺	2	3 ⁺	2	1	2	3	2	3	
13	3 ⁺	3	3	3	2	3 ⁺	3	3	2	3	2	3	
14	3 ⁺	3	3	3	2	3	3 ⁺	3	2	3	2	3	
15	3 ⁺	2	3	3 ⁺	2	3	2	2	2	3	1	2	
16	3 ⁺	2	3 ⁺	3 ⁺	2	2	2	2 ⁺	2 ⁺	2 ⁺	2	2 ⁺	.008
17	3 ⁺	2	3 ⁺	3 ⁺	2 ⁺	2 ⁺	2 ⁺	2	2	3 ⁺	2	2 ⁺	.004
18	2	2	2	2	2	2	1	1	2	2	1	2 ⁺	
p=	.014				.003			.033	.035		.000		

It is interesting to note that teachers, even the well prepared and active teachers, are in general not aware of where the obstacles come from. In their opinion a topic which has been taught is easier than a topic which has not, and they don't take into account the obstacles or the helps in understanding offered by common sense knowledge.

This kind of questionnaires has been important, and will be important, for the Italian school, in that they will allow teachers to face the problems and develop an awareness of both students' game rules, and their own game rules.

Quoting Bachelard again:

"J'ai souvent été frappé du fait que les professeurs de sciences, plus encore que les autres si c'est possible, ne comprennent pas qu'on ne comprenne pas... Ils n'ont pas réfléchi au fait que l'adolescent arrive dans la classe de Physique avec des connaissances empiriques déjà constituées: il s'agit alors, non pas d'acquiescer une culture expérimentale, mais bien de changer de culture expérimentale..." (Bachelard, 1938)

References

- Bachelard, G.
1938 "La Formation de l'Esprit Scientifique", Librairie Philosophique J.Vrin, Paris (1972)
- Bachelard, G.
1940 "La philosophie du non", Presses Universitaires de France, Paris
- Bateson, G.
1972 "Steps to an Ecology of Mind", Chandler Publishing Company, San Francisco
- Dupré', M., Noce, G., Vicentini-Missoni, M.
1981 "I modelli fisici prenewtoniani nella conoscenza degli adulti", Scuola e Città', n.2, pp.53-64

- Engel, E., Driver, R.
1981 "Investigating pupils' understanding of aspects of pressure", Proceedings of an International Workshop on Student's Representation, Ludwigsburg, Germany
- Ginzburg, C.
1979 "Spie-Radici di un paradigma indiziario" in *Crisi della ragione*, Gargani, A. Ed., Einaudi, Torino
- Gunstone, R., White, R.
1981 "Understanding of Gravity", *Science Education*, 65 (3), pp. 291-299
- Hewson, P.W.
1985 "Epistemological commitments in the learning of science: Examples from dynamics", *Eur. J. of Sci. Education*, vol.7, n.2, pp. 163-172
- Nussbaum, J., Novak, J.D.
1976 "Anassessment of children's concepts of Earth utilizing structured interviews", *Science Education*, 60 (4), pp. 535-550
- Nussbaum, J.
1979 "Children's conceptions of the Earth like a cosmic body: a cross age study", *Science Education*, 63, pp. 83-93
- Ruggiero, S., Cartelli, A., Dupre', F., Vicentini-Missoni, M.
1985 "Weight, gravity and air pressure: Mental representation by Italian middle school pupils", *Eur. J. of Sci. Education*, Vol.7, n.2, pp. 181-194
- Vicentini-Missoni, M.
1982 "Earth and gravity: Comparisons between adults' and children's knowledge", Proceedings of an International Workshop on Students' Representation, Ludwigsburg
- Watts, M., Zylbersztain, A.
1981 "A survey of some children's ideas about forces", *Physics Education*, 16, pp. 360-365
- Watzlawick, P., Weakland, J., Fisch, R.
1974 "Change", Norton & C., Italian version, Astrolabio, Roma

Engagement in Learning, Resistance to Schooling: Some Implications of Conceptual Teaching.

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The following joke appeared recently in the Reader's Digest. "The high school science class was checking over a test they had taken. Commenting on one item, the teacher remarked, 'This question was designed to make you think!' From the back of the class came, 'Trick question! Trick question.' "

I use this joke to make two points. The first is a point about conceptual understanding-oriented curricula (Pines and West, 1986). "Thinking" (in the student-centered sense of constructivist or generative learning theories) may not be a normal part of most classrooms. A conceptual curricula which values the students' own thoughts may be perceived by at least some students as a trick. The second point the joke raises is "Which students are most likely to see a conceptual curriculum as a trick: the goof-offs in the back row, or the good students sitting up front?" Based on comments made by researchers at the Special Interest Group on Cognitive Structure and Conceptual Change pre-session at AERA in April, 1987, there is some resistance to conceptual curricula among "bright" students in various parts of the globe. These academically-successful students seem to (at least initially) resist thinking for themselves rather than coming up with the (teacher-defined) "right answer." However this paper will also look at academically less successful students: the average and lower track students. These are the students who are considered "less able" or less interested in school. How do they respond to a conceptual curriculum?

In order to compare reactions to a conceptual curriculum across "ability" groups, I did an informal case study of eighth graders in science classes tracked based on "ability." (I am putting "ability" in quotes, as one of the issues I think conceptual curricula raise

is the definition of student "ability." Is it the ability to do well in school, by arbitrary criteria, or is it the ability to understand concepts and relate them to everyday life?) I wanted to observe 8th or 9th graders because middle school is the last point at which students in different tracks might get the same material. In some schools, students start getting different curricula as early as elementary school, especially with "enriched" classes for "gifted" students.

The teacher I observed works in a small rural school with a strong commitment to science and to the education of all its students. He taught science to 7th and 8th graders on all track levels. Many writers have described ways that teachers differentially treat students in various tracks (see Anyon, 1983; Contreras and Lee, 1987; Goodlad, 1984; Keddie, 1977; Kilbourn, 1986; and Oakes, 1985.). Because this teacher would be using the same material in all five 8th grade classes, any differences between how he handled the classes should be even more obvious.

A. THE CURRICULUM

My case study focussed on an unpublished unit about the particulate nature of matter based on Joseph Nussbaum's work, which the teacher (Douglas Larison) had access to through contacts at Cornell. While the unit was designed for use with sixth graders (Nussbaum, personal communication, 1987), the content is standard 8th grade material. The unit is a general introduction to particle theory which emphasizes observable characteristics of solids, liquids and gases, supplemented with visualization techniques (pretending to wear special goggles) to help conceptualize particles too small to see. There is no mention of atoms or molecules or atomic theory. As taught by Mr. Larison, the unit took approximately four weeks to complete. Classes were held for about 40 minutes per day, five days per week.

Changes of state were not explicitly addressed during the month-long introduction to particle theory, but my clinical interview included several questions regarding changes of state in water as a way of probing the students' ability to apply their understanding of particle theory to new material.

B. THE CASE STUDY.

Before designing the clinical interview, I observed one of the first lessons in the unit being taught to three of the five classes. The first period class was considered the advanced group, the second period class was average, the third was remedial, the fourth was average (but considered a "difficult" class), and the fifth class was also average. The first day I observed the advanced and two average groups. I was very pleasantly surprised to note nearly no differences in the way the teacher handled the classes or in the content he gave them. He commented later that he can move a little faster with advanced class, but consciously tries to give all groups the same material. (Larison, personal communication, 1985.)

The major difference I noticed between the classes was in how the students responded to a conceptual curriculum. Among the academically more successful students (the "advanced" class), there seemed to be a resistance to expressing their own thoughts, which contrasted with a surprising willingness to express their own ideas among the average classes. I therefore designed the rest of my study so that I could compare students in different tracks in terms of their

1. engagement with a conceptual curriculum
2. engagement with schooling in general
3. understanding of the content
4. test performance

To further check my initial observations of differences in how students in different tracks respond to the same conceptually-

oriented material, I observed all five classes during a lesson towards the end of the unit. I also returned the week after the unit ended to conduct clinical interviews and administer a brief written questionnaire.

As indicators of student *understanding of the content*, I conducted clinical interviews with 2-4 students from each class (which ranged in size from 8-15 students) a week after the unit was completed. The students names were drawn randomly, alternately from a pool of males and a pool of females. At the start of the interview, the students were given a paper with three flasks drawn on it and were asked to "make a conceptual drawing of each flask to show what the particles in it would look like if you were wearing "special goggles" to make the particles visible." There were three actual flasks on the table which matched the conditions the drawing was to represent: an open flask with just air, an open flask with water, and a closed flask which (supposedly) had all the air pumped out. This task was similar to an exercise they had had in class. The students were then asked to explain their drawings. This was followed by a discussion of changes of state in water (what would happen to water in the open flask was discussed as a probe re: evaporation, and frost on car windows as a probe re: condensation). The discussion of changes of state in water (which had not yet been covered in class) was included as a way of checking understanding because the students should have had experience with it in everyday life, but would not be feeding me material from the teacher. In some interviews, students were also asked epistemological questions about "the world of science" and "the real world."

At the end of the interview, I had each student fill out a very brief questionnaire. In order to investigate student *engagement with a conceptual curriculum* and *engagement with schooling in general*, the questionnaire asked students to rate how comfortable they felt with components of a conceptual curriculum as well as more standard classroom activities. It also

asked how much time they spent on school work outside of class, and where they did most of their studying. In addition, I asked the teacher to rate each student for overall "willingness" to engage in schooling, not just during this unit, on a rough scale of 1-10.

As indicators of *test performance*, overall unit test scores and concept maps made by students during the final unit test were obtained from the teacher for each student interviewed. (In this instance, the concept maps had become a standard part of classroom testing, with all the negative connotations that might bring. This will be briefly discussed later.)

C. COMMENTS ON THE RESULTS

1. Classroom observations: engagement with a conceptual curriculum. As noted above, during the first set of observations the first period class (advanced) had the most difficulty expressing their own thoughts rather than reciting superficial knowledge. When challenged by the teacher on their persistent use of terms such as "molecule," students admitted they had known that particle theory had to do with molecules because they "read it in the encyclopedia" or "my older sister was explaining it to me." They appeared to be fishing for what they thought the teacher wanted to hear. Statements such as "a molecule is part of an atom" indicated that students' understanding did not match their vocabulary.

Students in the 2nd period class (average) appeared to be quite engaged with thinking about questions raised by the teacher, such as "what would be between the air particles?" They had a much easier time than the advanced class using terms such as "nothing" and "space" to indicate what is between air particles.

During this class, the test on the previous unit was returned. The teacher commented to the class that some students who seemed to at least partially know the material left many of the

short essay questions completely blank, thus losing the chance for any credit. He later commented to me that he was somewhat puzzled by students who turned in incomplete exams before the end of the testing period when he knew they knew some of the answers (Larison, personal communication, 1985).

During this first set of observations, an interesting contrast between the classes was noted during a demonstration of air being compressed within an airtight syringe. The teacher did the demonstration under water so that any escaping air could be seen as bubbles. When he asked the advanced class "What did you see?" they responded, "Bubbles." He repeated the demonstration and asked, "See bubbles that time?" They "read" the teacher correctly, and responded, "no," even though I observed the same number of bubbles both times. When the average classes insisted they saw bubbles escaping from the syringe and were not so willing to change their answer based on clues from the teacher, the teacher figured out they were referring to small bubbles leaving the outside surface of the syringe. He then compressed an open syringe of air underwater, showing that many large bubbles escaped under that circumstance. The willingness of the advanced students to feed "correct" answers to the teacher may have kept them from understanding the point of the demonstration (air has empty space between particles and therefore can be compressed under pressure).

During the second set of observations, held three weeks later, some similar differences were noted between classes. The lesson focused on whether any change had occurred over the weekend in a flask with a blue liquid in the bottom and clear water on the top. During a lab the previous Friday, the class had been asked to check for any mixing between the two liquids after a 10 minute interval (none had been observed). Monday morning the first period class (advanced) was asked if the materials were mixing. One student answered yes, they were starting to mix, but hadn't

had enough time on Friday. When the teacher challenged this (correct) answer and asked, "Maybe I screwed up on Friday and didn't allow enough time?" the students decided the liquids were not mixing. When the teacher prompted them for a different answer, ("Because you're not jumping out of your chairs, I suspect you didn't see what you should have."), the students started saying "Maybe it started mixing a little." Because the students were so busy second-guessing the teacher, they took 14 minutes deciding whether or not the two liquids were mixing. Only one student asked a question ("Are particles in solids?").

In contrast, the second (average) class was prompted more directly towards the right answer. Teacher (T): "Is that how it looked?" Student (S): "Sort of." T: "I hope not. What happened over the weekend?" S: "It mixed; it's not a straight line." (Because the teacher hinted directly that they should have seen a change, I didn't get to see whether these students would have second-guessed the teacher as persistently as the "advanced" class did.) After 5 minutes of discussion regarding how two liquids could mix, one student suggested, "Maybe it's made up of particles, but it took longer to move [than gases do]?"

The third class (remedial) got to the point quickly, and the teacher did not challenge their (correct) responses. In this class, the teacher explained more things directly, rather than trying to elicit answers from students.

The fourth class (average, but considered a "difficult" class with lots of discipline problems) quickly got to the essence of the lesson. S1: "It sort of like mixed, spread out." S2 immediately added: "It's got particles in it." Later the teacher asked: "How come we needed more time?" S: "Because more [particles] slowed mixing down." This was followed by a discussion (by the students) of why liquids can't be compressed as easily as gases (too many particles; not enough empty space). However, the students weren't sure if water had empty space in it until the

teacher explained that water (like gases) had particles and empty space. Mixed in with this apparently productive lesson were quite a few reprimands when students didn't seem focused, including sending one student out of the room.

The final class of the day (average) was conducted somewhat differently from the earlier lessons, although most of the changes reflected a gradual evolution throughout the course of the day. One of the main advantages of teaching the same material to multiple classes is that teachers can refine their approach based on feedback from the students. By the last class, both the students and the teacher had less energy, but the teacher also understood which points the students tended to be confused about. He therefore structured the discussion more productively, primarily by using appropriate advance organizers, such as reviewing a previous lab (regarding the mixing of two gases) and asking whether liquids have particles before asking whether the two liquids had changed over the weekend. Also, being realistic, a class meeting after lunch was likely to have heard from students in earlier classes that the "correct" answer was that the two liquids were mixing.

In general, students in the non-advanced classes seemed more comfortable asking "stupid" but key questions. When one student in the last class said to draw water particles "right tight," another said water couldn't have moved if there was no empty space. Later, another student asked what would happen if you breathed only empty space (instead of air). When another student said, "Yeah, how can there be nothing," lots of heads nodded in agreement. While there were still aspects of particle theory these students were having trouble accepting, they seemed to be well engaged with the central ideas relating to particle theory.

This sort of lively exchange was observed in all the classes except the first period "advanced" class, which had spent almost half the class deciding whether the two liquids had mixed. I'm not sure

they would have dared asked so basic a question as "How can there be nothing?" which showed the others students were really thinking about one of the main implications of particle theory: that there are spaces between the particles with nothing in them. The clinical interviews gave further indications that many of the advanced students may have been more engaged with schooling, while many of the average and remedial students were more engaged with learning.

2. Evaluation of student understanding.

As a whole the advanced students did better than the other students on all evaluation criteria. But the "spread" between tracks was much less than might have been expected, especially during the clinical interviews.

a. Test performance. On the final unit tests, most students (11/17) received grades between 73 and 86. Only 2 students received grades below 70, and only two students received grades over 86 (see Table I). When averaging the results by class, the remedial class was not very different from the difficult average class, and the other two average classes were between them and the advanced class. Looking at the individual scores shows even greater overlap between the groups; often one student's very high or very low score brought the group's average up or down. [Results of individual students of particular interest are in boldface in Table I.]

I rated the concept maps by giving positive points for concepts apparently correctly understood, whether they were "correctly" mapped or not. In most cases this corresponded closely with the teacher's grades, where points were taken off for incorrect conceptual relationships. Most of the discrepancies between my rating and the teacher's grading occurred with students who had not yet mastered the technique of making the maps.

TABLE I
EVALUATION RESULTS

CLASS	stud. #	gen. m/f	unit test		clinical interview	
			TEST %	MAP /13	DRAW. /3	interview comments
I ADV.	1	m	85	13	3	water-; part NA
	2	f	85	12	2	water NA; part NA
	3	f	96	12.5	(2)	no interview
	9	m	86	12.5	3	water -; part -
	10	f	84	13	1	water -; part +
	AVERAGES		87.5	12.6	2.2	
II AVE.	4	f	75	11	2	water NA; part NA
	11	m	73	10.5	2	water NA; part NA
	12	f	92	9.5	2	water+; part+/-
	AVERAGES		80	10.3	2	
III REM.	5	f	70	8.5	1	water NA; part -
	6	m	78	8.5	1	water +; part +/-
	13	f	58	5.8	1	water+; part+/-
	14	m	78	10	2	water NA; part ++
	AVERAGES		71	8.2	1.3	
IV AVE. difficult	7	f	78	8	2	water +; part +/-
	8	m	50	NA	2	water+; part+
	15	m	70	6	3	water +/-; part+/-
	16	m	85	5.8	1	water NA; part NA
	AVERAGES		71	6.6	2	
V AVE.	17	m	86	8.5	2	water NA; part NA
	18	f	77	12.5	1	water NA; part NA
	AVERAGES		81.5	10.5	1.5	

KEY

ADV. = advanced
 AVE. = average
 REM. = remedial
 ++ : very good understanding
 + : good understanding
 +/- : partial understanding
 - : poor understanding
 NA: not available (usually due to time limits)
 water: changes of state of water (everyday instances)
 part: particle theory (explanation of conceptual drawing)

b. **Clinical interviews.** There were two main problems with the clinical interviews: their subjective nature, and their variability. In transcribing the tapes, I found that I had often "led" the students, mostly by "putting words in their mouths" when they seemed to have an idea but lacked the vocabulary to express it. The variability was largely due to time pressures, as the same content didn't get covered with each student. (As the study was a preliminary "fishing expedition," I sometimes started the interview with the epistemological questions, in order to have some students answer each type of question.) I did not formally code the interviews. However I did rate the students on a four point scale for their explanations of their conceptual drawings, abbreviated "part." on Table I. I used the same scale to rate students' understanding of changes of state in water, abbreviated "water."

The main advantage of the clinical interviews was that I was able to probe students' understanding in ways which did not come out with any other technique. The interviews clearly pointed up the inadequacy of conventional ways of assessing students' "mastery" of content. For example, Student 1 (advanced class) seemed to have a good grasp of the material from his test scores, concept maps, and conceptual drawing (85%, 13/13, and 3/3 respectively), but the interview revealed a basic lack of understanding masked by an ability to recreate what the teacher had presented. On the other extreme, Student 8 (average difficult) only got 50% on the test, yet he made a good conceptual drawing (2/3), and his explanation of the drawing and discussion of changes of state indicated a well above average understanding of the particulate nature of matter.

3. Questionnaire: engagement with a conceptual curriculum and engagement with schooling in general.

As the end of the clinical interview, the students were asked to fill out a brief questionnaire about their experiences in science

class. The items were scored on a 5 point Likert scale, and averaged for each class and for the sample as a whole. Since there were only minimal differences between the average scores for each class, the average results for the whole sample are listed in Table II, ranked from the most enjoyed to the least enjoyed activities. (See Appendix A for individual results.)

TABLE II
SCHOOL TASK QUESTIONNAIRE

RANK	ITEM	AVERAGE SCORE
1	doing a lab myself	1.1
2	watching a lab demonstration	1.7
3	listening to other students	2.5
4-5	asking questions	2.8
4-5	writing on the blackboard	2.8
6	listening to the teacher explain	3.0
7	copying from the blackboard	3.2
8	making vee diagrams	3.5
9	making concept maps	3.7

SCORE KEY

- 1 = enjoy a lot
- 2 = enjoy
- 3 = o.k.
- 4 = don't enjoy much
- 5 = don't enjoy at all

Not surprisingly, the students seem to generally prefer activities and discussions to written work. All the students enjoyed "doing a lab myself." They enjoyed "watching [the teacher do] a lab demonstration" almost as much. Based on classroom observations, they also seemed to appreciate having their own ideas attended to, either by the teacher or by other students. Half the students said they enjoy "listening to other students;" the others said it was

"o.k.," with only one student rating it a "4." "Asking questions" and "writing on the blackboard" had less enthusiasts, but few negatives responses. "Listening to the teacher" was evenly split among enthusiastic, neutral, and unenthusiastic students. "Copying from the blackboard" was largely a neutral activity, with no very enthusiastic students. The activities receiving the lowest ratings were "making vee diagrams" and "making concept maps." They also received many more strongly negative responses (4's and 5's) than any other item. 9/17 students rated concepts maps as being unenjoyable; 10/17 students rated vee diagrams as unenjoyable. (See Appendix A.)

Since conceptual curricula such as this unit are supposed to value students' ideas in order to help them change their ideas, concept maps and vee diagrams should be expected to have had a higher rating. In this case their low rank was consistent with my observation that they were used more as vehicles for accountability (homework, lab reports, and tests) than as a way for students to think through and express their own ideas. The development of one concept map by the whole class may have given them the impression there was a single correct concept map. During the interviews, students also sometimes made inappropriate references to concepts, principles and theories, which indicated some confusion about how to use vee diagrams. They were intended to be a way for students to set lab experiences in a theoretical context. I think these results are more a comment on how vee diagrams were used in this particular class (a format for lab reports and therefore the basis for lab grades) than an indication of student attitudes towards metacognitive tools in general. During classroom observations and clinical interviews, the students were very willing to make conceptual drawings and seemed to enjoy sharing them with others. (Unfortunately, conceptual drawings were not included on the school task questionnaire.)

The student who rated the most activities "unenjoyable" (#8) rated very low (3/10) on the teacher's "willingness scale" and did very poorly on the unit test (50%). He is especially interesting because his interview indicated he was quite engaged with the concepts in this unit and connected them with his everyday life. (His concept map was not available because he moved from the area shortly after the unit was finished.)

The questionnaire also included some questions about where and how much homework students did. All the students said they did all their homework at home (as opposed to at school or on the bus), except # 8, who only did homework at school (which probably means he didn't do much; he didn't answer the question about time). Most students spent between fifteen and thirty minutes on their assignments, including studying for tests. However, many of the students who did poorly on tests studied more than 1/2 hour (self-reported). This may indicate a lack of appropriate study skills, or it may reflect an artifact of the questionnaire (students who do poorly may not want to admit not studying).

When discussing the students' generally high level of engagement in the unit (noted in the observations and confirmed in the questionnaire) with the teacher, he said that this unit was based more in the real world than most units they get, and that he made a special effort to pay more attention to their ideas than he does while teaching other more conventional units (Larison, personal communication, 1987).

D. QUESTIONS FOR FURTHER EXPLORATION.

What does ability mean, when low track students can grasp basic ideas and high track students resist thinking for themselves? The nature of the educational process changes with conceptual understanding curricula, and this has ramifications both within

and beyond the classroom. While this informal study can't give any definitive answers, it can help us clarify some of the issues.

1. What kind of content should be taught to whom?

Eighth grade general science is perhaps the last course the students in this study will take which can be considered part of their "general education," common to all students of that age. In many schools tracking starts even earlier, and means that students in different classes get different content, perhaps taught with different approaches (see Anyon, Contreras et al., Goodlad, Kilbourn, Oakes). This case study indicates that one of the advantages of conceptual understanding curricula is their potential to work well for traditionally less successful students. A much wider range of students can benefit from a curriculum which builds on their own ideas and prior understandings, especially if it helps them connect these ideas with their everyday lives.

In the epistemological portion of the interviews, the "advanced" students tended to see the relevance of the unit to their further studies or to potential careers as scientists. Most of the lower track students saw the academic elements of the course as largely irrelevant, but often found ways of applying basic concepts to their everyday life. If connected to everyday life rather than to higher education, topics such as particle theory can be very appropriate for all students. If conceptual understanding curricula can teach basic concepts to a wide range of students, then "general science as general education" may be feasible throughout middle school, as well as in elementary school.

2. How should students be evaluated?

Even when the teacher brings nearly the same material, taught in nearly the same way, to students from different tracks, their prior relationship to schooling in general will affect how they interact with that particular piece of curriculum. In the case of conceptual understanding curricula, the top track students may

do better in some areas (paper and pencil tests, homework, etc.), and lower track students may do better in other areas (willingness to engage with the concepts, seeing connections to everyday life.) The discrepancies between the students' performances on the unit tests and their actual understandings as shown in the clinical interview indicate that there are special problems in evaluating the progress of individual students taught a conceptual-understanding curriculum in a large group setting. First, there has to be careful articulation between the way students are taught and the way they are tested. If they are taught in a way which expects them to express their own ideas (as many constructivist and some conceptual change curricula do), then they should not be tested based on the "one correct answer" the teacher is looking for. There should be enough variability in how they are allowed to express their ideas when being evaluated that they will give their own ideas. If students' actual understanding of central concepts is what is to be evaluated, then they have to feel safe expressing their own ideas, rather than feeding the teacher what they think s/he wants to hear. Conversely, students who are skilled at giving the expected answers back to the teacher need to be probed carefully in order to find out what their own thoughts are.

Even when grades are partially based on such "conceptual" techniques as concept maps and vee diagrams, students' general attitudes towards homework and testing may make it difficult to use these tools to assess actual understandings. Metacognitive tools are supposed to aid the learning process; they are a way for the student to become aware of (and therefore reinforce or correct) their own ideas. In this study, concept maps and vee diagrams were used primarily to measure students' ability to match the teacher's template. Only in their conceptual drawings was variability allowed and their own ideas valued. While clinical interviews are not feasible as a regular way of evaluating student understanding by classroom teachers, they show potential as a way for teachers to spot check and monitor

class progress. Metacognitive tools such as conceptual drawings, concept maps, and possibly vee diagrams also show promise as evaluation tools for conceptual-understanding curricula, but only if they are consistently used to value students' actual understandings (eg, in a mastery program where they get multiple shots at correcting incomplete or incorrect ideas). Otherwise these techniques become just another part of the regurgitation game.

3. Are there discrepancies between the goals we have as educational researchers and curriculum developers and the functional goals which operate within classrooms? While making all students scientifically literate is an oft-espoused goal, few science courses are taught in ways that most students can understand and with explicit connections to everyday life. There are various reasons for discrepancies between goals and practice (see for example, Keddie, 1977.) A conceptual understanding curriculum common to students in all tracks may find resistance among some parents, within school systems, or by state or national education systems, etc. Among other factors, a common curriculum taught well to a wide range of students may not serve as an adequate screen, separating potential scientists and from non-scientists (Fensham, 1986). A conceptual understanding curriculum is time-consuming and therefore expensive. It may work well for students who do not usually receive expensive academic resources. It may not give much advantage to students who are otherwise likely to be "the cream of the crop." Conceptual understanding-oriented curricula will only become widespread in their use if schools make a real commitment to teaching science well to all students. The rhetoric of excellence and equity in national reports remains empty unless we explore curricular approaches which work well for a broader range of pupils. If we do have a commitment to scientific literacy for all students, then the ability of conceptual understanding curricula to engage students in learning (not just in schooling) makes them worth developing further.

REFERENCES

- Anyon, Jean. "Social Class and the Hidden Curriculum of Work." In H. Giroux and D. Purpel, The Hidden Curriculum and Moral Education. Berkeley: McCutchan, 1983.
- Contreras, Armando and Okhee Lee. "Differential Treatment of Students by Middle School Science Teachers: Unintended Cultural Bias." Paper presented at the annual meeting of NARST, Washington, DC, April, 1987.
- Fensham, Peter. "Science for All." Paper presented at the annual meeting of AERA, San Francisco, April, 1986.
- Goodlad, John. A Place Called School. NY: McGraw-Hill Book Co., 1984.
- Keddie, Nell. "Classroom Knowledge." In A. Bellack and H. Kliebard, ed., Curriculum and Evaluation. Berkeley: McCutchan, 1977.
- Kilbourn, Brent. "Concepts for Reflecting on Teaching Non-academic Students." Paper presented at the annual meeting of AERA, San Francisco, April, 1987.
- Novick, Shimshen and Joseph Nussbaum. "Junior High School Pupils' Understanding of the Particulate Nature of Matter: An Interview Study." Science Education 62 (3): 273-281 (1978).
- Oakes, Jeannie. Keeping Track: How Schools Structure Inequality. New Haven: Yale University Press, 1985.
- Pines, Leon and Leo West. "Conceptual Understanding and Science Learning: An Interpretation of Research within a Sources-of-knowledge Framework." Science Education, 70 (5): 583-608 (1986).

APPENDIX A
SCHOOL TASK QUESTIONNAIRE

Ratings by individuals

CLASS	stu. #	gen. m/f	a <i>copying books for other kids</i>	b <i>giving books to other kids</i>	c <i>reading books to other kids</i>	d <i>reading books myself</i>	e <i>reading books myself</i>	f <i>reading books myself</i>	g <i>reading books myself</i>	h <i>reading books myself</i>	i <i>reading books myself</i>	total
I	1	m	3	2	3	4	1	4	3	5	3	28
	2	f	3	1	2	2	1	4	2	4	1	20
ADV.	9	m	4	2	3	5	1	3	1	3	5	27
	10	f	3	1	2	3	1	4	2	4	3	23
AVERAGE			3.3	1.5	2.5	3.5	1	3.8	2	4	3	24.5
II	4	f	4	2	3	2	1	3	2	4	3	24
	11	m	3	1	3	2	1	3	4	3	4	24
AVE.	12	f	3	3	4	2	1	5	3	4	3	28
AVERAGE			3.3	2	3.3	2	1	3.6	3	3.6	3.3	25
III	5	f	3	2	4	2	1	3	3	3	2	23
	6	m	4	1	1	1	1	5	2	4	3	22
REM.	13	f	2	1	2	3	1	3	3	1	3	19
	14	m	3	2	2	3	1	3	2	4	3	23
AVERAGE			3	1.5	2.3	2.3	1	3.5	3.3	3	2.8	22
IV	7	f	3	2	3	4	1	3	2	4	1	23
	8	m	5	2	5	5	1	5	3	5	3	34
AVE.	15	m	3	2	3	2	1	4	3	4	3	25
diff.	16	m	3	1	3	5	1	4	2	3	3	25
AVERAGE			3.5	1.8	3.5	4	1	4	2.5	4	2.5	27
V	17	m	2	2	2	3	2	4	3	3	2	23
AVE.	18	f	3	2	3	3	2	3	3	3	3	25
AVERAGE			2.5	2	2.5	3	2	3.5	3	3	2.5	24

SCORE KEY

- 1 = enjoy a lot
- 2 = enjoy
- 3 = o.k.
- 4 = don't enjoy much
- 5 = don't enjoy at all

634

APPENDIX B
ENGAGEMENT IN SCHOOLING:
"WILLINGNESS" RATING BY TEACHER

CLASS	stud. #	gen. m/f	willingness
I	1	m	9
	2	f	9
ADV.	9	m	8
	10	f	9
AVERAGE			8.8
II	4	f	8
	11	m	7
AVE.	12	f	8
AVERAGE			7.6
III	5	f	5
	6	m	9
REM.	13	f	6
	14	m	8
AVERAGE			7
IV	7	f	5
	8	m	3
AVE.	15	m	6
difficult	16	m	9
AVERAGE			5.8
V	17	m	6
AVE.	18	f	5
AVERAGE			5.5

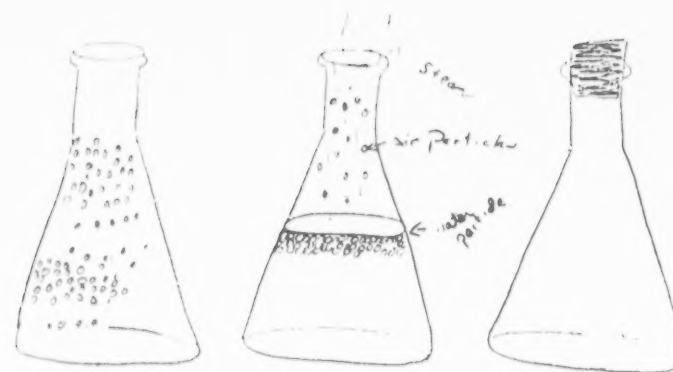
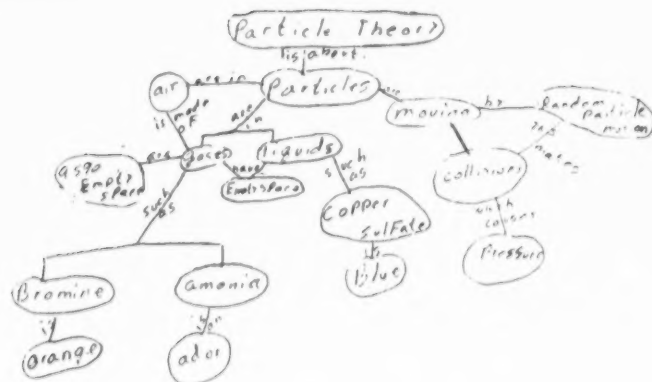
KEY: 10 = high willingness; 1 = low willingness

635

STUDENT # 8

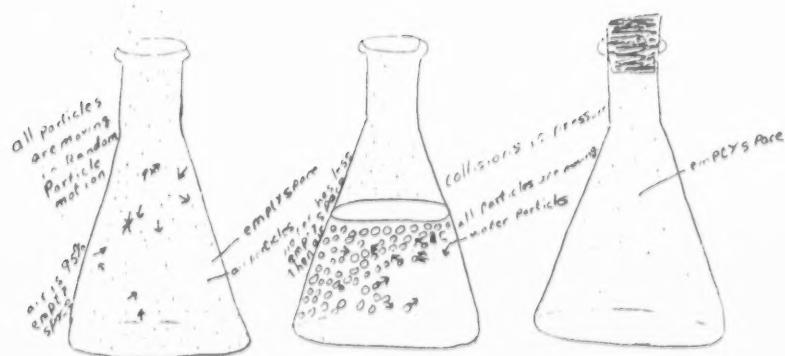
CONCEPT MAP FROM UNIT TEST

Student # 1



CONCEPTUAL DRAWING OF THREE FLASKS

STUDENT # 1



636

637

Overview

For the past decade cognitive process researchers have measured the prevalence of misconceptions in math and science among groups of students. Often the measure is accomplished through the use of an open-ended or multiple-choice question administered singly or with few additional items. The data achieved is used to support hypotheses about the prevalence and resilience of one or several misconceptions. Briefly, a misconception is a person's conceptualization of a problem or phenomenon that generally is reasonable to themselves but at variance from the conceptualization of an "expert" in the field from which the problem came. Since the objective of the test item is to corroborate experiential observations in the classroom or surfaced misconceptions in clinical interviews, little if any analysis of reliability and validity has been conducted on the items themselves. One naive but frequent complaint about items which evoke misconceptions is that they are "tricky". The intention of the item is not to trick the student, but to test for conceptual understanding by placing known misconceptions as options on the item. If the examinee's difficulty with the item results from an inadequate grasp of the concept which the item is testing, then the item and the "tricky" distractor has proved its usefulness.

Research indicates that misconceptions are widespread and resistant to the benefits of instruction, [Clement, 1982; Fredette, & Lochhead, 1980; Minstrell, 1986]. The predominant observation of misconceptions researchers is that misconceptions in the student must be addressed and overcome before a new and better understanding is attained. Misconceptions may be viewed as both a stumbling block for students and a signpost for the teacher. It follows that misconceptions ought to be incorporated into standardized

tests which attempt to assess the level of understanding among examinees.

This study examines some of the problems which arise from incorporating misconceptions into a standardized placement exam for the selection of students into a college remedial math course. Some of these problems are:

- * Items containing misconceptions [MI, misconception item] are more difficult than items which do not contain misconceptions. [Low p-values]
- * MIs correlate poorly with items which do not contain misconceptions. [Low item/total-test-score point biserial correlations]
- * In a multiple-choice MI the distractor which contains the misconception is often chosen more frequently than the correct answer even by students who are proficient with non-MIs. [Positive or near-zero distractor/total-test-score point biserial correlations on distractors with misconceptions]

All of the measures listed above are reliability measures from classical test theory [CTT] and would suggest removal of the MI from the test or removal of the misconception-distractor from the item.

An analysis of MIs using Item Response Theory [IRT] indicates that MIs are in fact useful items. Developed primarily by Lord (1952, 1953a, 1953b), IRT attempts to relate the likelihood of a correct response to an item to an individual's ability. Assuming that the test measures only one trait (unidimensionality), then the probability of a correct response to an item depends on two variables only: the item and the examinee. Quantitatively, the examinee is assigned one number (for ability) while the item is assigned one, two or three numbers, (for discrimination, difficulty and pseudo-chance "guessing") depending upon the specific IRT model used. The present study uses a modified three-

parameter logistic model which derives from the work of Birnbaum (1957, 1958a, 1958b, 1968) and Lord (1974). The following were observed:

- * MIs are difficult, but not much more difficult than non-MIs.
- * MIs discriminate well among examinees, especially at the high-end of abilities.
- * There appears to be less guessing on MIs than on non-MIs.

While CTT is useful in the analysis of MIs, it is inadequate in that cognitively interesting and valid items may be discarded. IRT adds qualitatively different information to item analyses which contributes significantly to the selection and interpretation of MIs. It is suggested that tests which incorporate misconceptions into items be analyzed with both CTT and IRT.

Although validity was the primary motivation for this study, there are few quantitative measures of validity appearing. Following Anastasi's (1986) recommendation, validity was built into the present test from the outset rather than being addressed in the final stages of the test's development. The items in the test reflect the content of the course which students were placing out of, and the items with misconceptions tested the degree of understanding of specific topics taught in the course. Prior research, psychological theory and teaching experience contributed substantially to the generation of these items. Nevertheless, it would be difficult to ascertain construct validity since there is as yet no concisely described psychological trait which accurately conveys the kind of understanding needed to succeed on mathematics items which contain misconceptions. While the remedial math course is aptly described as "Quantitative Reasoning" one would be hard-pressed to find a suitable description that would lend

itself to careful quantification. Perhaps the most useful measure of construct validity is the overall reliability of the test to indicate the presence of a cluster of skills with a high degree of intercorrelation. Furthermore, no suitable criterion has been found from which a criterion validity correlation may be conducted. With the development of new tests of similar construct and content, criterion validation will be possible.

DATA COLLECTION

The data for this study represents the test results of 618 freshmen who were diagnosed as math weak from a previous placement test. The Math Department at the University of Massachusetts tests all incoming freshmen to ascertain their level of math ability. Those students who demonstrate a need for a remedial math course are then sent to the Basic Math Program of the Cognitive Processes Research Group [CPRG] for placement into either of two remedial courses. Math 010 is a remedial course in quantitative reasoning, which mainly teaches arithmetic. More specifically, the content of Math 010 is: fractions, decimals, percents, exponents, solving linear equations, simple applied geometry, and algebra translation tasks. The second level of the remedial program is a course entitled Math 011, Introductory Algebra. Both courses stress conceptual understanding in addition to rote algorithmic computation and symbol manipulation. Story problems and problems which incorporate or elicit misconceptions are often used to foster and challenge the students' understandings.

The CPRG placement exam is composed of 28 items which reflect all areas of course content for Math 010. (See appendix 1). Students who score at least sixteen of the items correctly may enroll in Math 011. Anyone scoring less than sixteen correct must first take Math 010. All of the items are five-option multiple-choice items which are

machine scored. Several of the items contain common misconceptions which appear in research (Rosnick & Clement, 1980; Benander & Clement, 1985), and which six years of experience teaching the course indicates are prevalent among the 010 student population. The content on the placement exam is similar to a Math 010 final examination, although the format is quite different since the placement exam is the only exam in Math 010 which is multiple choice.

Instructors administered the test on the second day of classes to all entering students in Math 010 and Math 011, regardless of preregistration. The first day of classes consisted of administrative details only. Exactly thirty minutes was allowed for testing. Instructors reported that virtually everyone had finished in the allotted time. Following scoring, students were reassigned to their proper classes; usually two class days after the exam date.

The exam was administered to two separate groups in the Fall and Spring semesters. Measures were instituted to secure the exam to prevent cheating. Although the testing times differed, the test was identical both semesters, and since all of the students had been diagnosed math weak from a previous math department placement exam (composed mostly of items from the Mathematical Association of America item bank), it can be safely assumed that the two groups are similar in ability, and that test conditions for both groups were also similar. Because the Item Response Theory (IRT) analysis is more reliable with a $n > 600$, the data from both groups were merged.

DATA ANALYSIS

Two computer software packages were used in the analysis of the data. MERMAC (1971) uses Classical Test Theory (CTT) to analyze and report test and item statistics together with individual student response reports. LOGIST

(1982) uses Item Response Theory (IRT) to analyze item parameters and individual student abilities. A more detailed description of these analyses follows.

MERMAC

A summary of test statistics, as reported by MERMAC, (Bussel et al, 1971) appears in Appendix 2. The close match between the mean and median scores indicates a near normal distribution which was also evident in the frequency distribution reported by MERMAC (not shown here). The average test difficulty,

$$\frac{\text{mean score}}{\text{Total \# of Items}} = \bar{P} = 0.43$$

is low by comparison to most math ability tests which have $p > 0.6$. [Tinkelman, 1971], but is understandable in consideration of the group. Although it is surprising that college freshmen would do so poorly on so simple a test as this, one would not expect high scores from a group already diagnosed as needy of remediation. Low p-values also affect the overall test reliability. The optimum average item difficulty for a five-option multiple-choice test is about $p=0.7$ (Tinkelman, 1971). The error variance due to chance is decreased since less guessing occurs on easier items than on difficult ones. Consequently, the test reliability is increased. In fact, the CPRG test reliability, calculated with the Kuder-Richardson Formula #20, is reported at 0.78, which is quite acceptable considering the few number of items and the homogeneity of the group. It should also be noted that items were not removed for being too difficult, a phenomenon common to many math tests (Leinwand, 1983), since this would invalidate a test which attempts to ascertain conceptual understanding.

MERMAC also provides item analyses which provide information in three different formats. A dot graph of

student groups distinguished by quintiles is plotted against the percent correct for that item. A clearly increasing shape indicates a relatively high correlation between that item and the rest of the test.

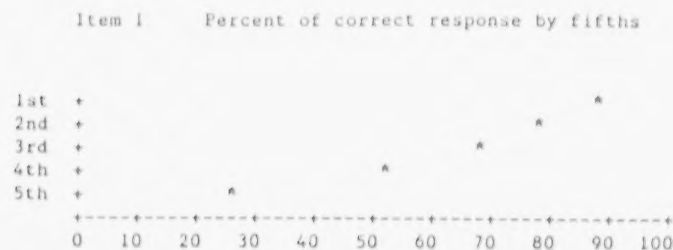


Figure 1

One difficulty in interpreting these graphs comes from the fact that the quantities are not at equal intervals in terms of score range. Students in the first quintile scored in the range between 17 and 26 items correct while those in the fifth quintile scored between 0 and 7 correct. The mid-three quintiles each had a range of only three items. This would of course be the case for any normally distributed test population. MERMAC mitigates this difficulty by providing a matrix of the number of responses made by each quintile to each item option and the number of omits for each item. The overall proportion of students selecting each of the distractors is also reported above the option/total test score point biserial (see appendix 3).

Option/Total-Test-Score Point-Biserial Correlation

$$r_{x} = \frac{X_d - X}{S_x} \sqrt{\frac{P_i}{1 - P_i}}$$

where: X_o = mean of X scores among examinees selecting option O
 X = mean of X scores among all examinees
 S_x = standard deviation of all scores
 P_i = item difficulty

When the option is the correct response (marked with parentheses), then the item total-test-score point-biserial correlation is calculated. One would expect good items to have a positive correlation on the correct response and negative correlations for all of the distractors. The average item/test correlations for mathematics items is about 0.6, which is high when compared with the average item-test correlation for social studies items which runs about 0.4 (Tinkelman, 1971). The present test has a comparatively low item-test correlation of 0.376, which occurs mainly because of the presence of MI's, which have lower item-test correlations and positive distractor-test correlations. This phenomenon will be considered more thoroughly in another section.

LOGIST

The LOGIST computer program (Wingersky, 1983), reports item analyses on the basis of an Item Response Theory [IRT] test model. [For a thorough review of IRT, see Hambleton and Swaminathan (1985), and Hambleton (1983).] As mentioned earlier, IRT estimates the probability of a correct response to an item from an individual at any ability. The mathematical model used by the LOGIST program is the three-parameter logistic model which is a modification of the two-parameter logistic model developed by Birnbaum (1957). The three-parameter model is described by the function:

$$P_i(\theta) = C_i + (1 - C_i) \cdot \left[\frac{e^{1.7a_i(\theta - b_i)}}{1 + e^{1.7a_i(\theta - b_i)}} \right]$$

(i = 1, 2, ..., n)

where:

$P_i(\theta)$ = the probability that an examinee with ability level θ answers item i correctly;

b_i = the item difficulty parameter which is the point on the ability scale where an examinee has a

$$\frac{1 + c_i}{2}$$

probability of answering correctly.

a_i = the item discrimination parameter.

c_i = the pseudo-chance level parameter which represents the probability of low ability examinees correctly answering an item.

The following item characteristic curve [ICC] is a graphical representation of the result of LOGIST item parameters for item #20 on the placement test:

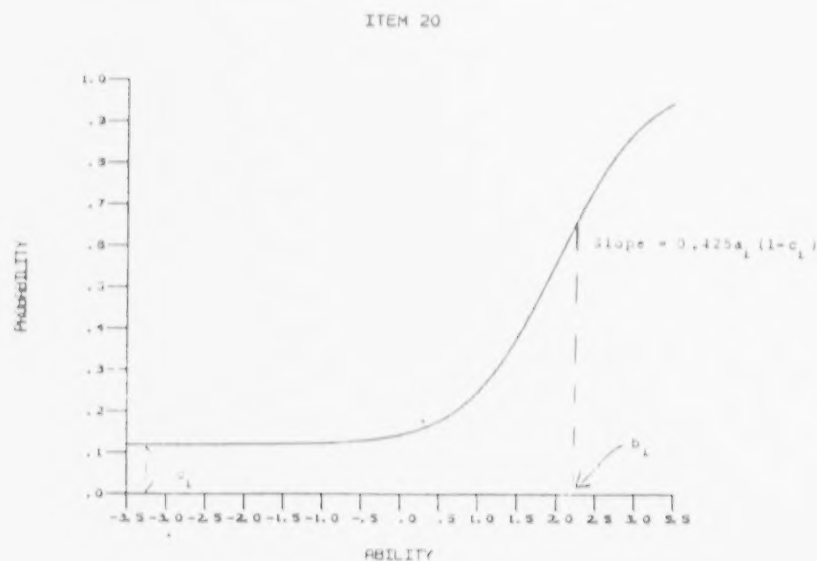


Figure 2

The ability scale is on an axis from negative infinity to positive infinity, and is standardized with a mean of 0 and a standard deviation of 1. Theoretically the b-values can be any number, although b-values are generally in the range

of -3 to 3. The lower asymptote indicates the level of guessing. On this particular item the c-parameter is just above 0.1. The fact that this is a five-option item implies that there was less guessing on this item than random probability would suggest. The b-parameter is about 2.2, which suggests that this is a relatively difficult item. The steepness of the curve is a measure of the discrimination of the item. The position of the inflection point on the ability scale is the b-value, and besides difficulty, it indicates at which ability level the item is most discriminating.

Fitting The Model To The Data

After obtaining item parameters using LOGIST a goodness of fit study (Hambleton and Murray, 1983) was conducted to evaluate the success of the three-parameter logistic model in predicting the observed data. A computer program prepared by Murray, Hambleton and Simon (1983) was used to conduct a residual analysis of the logistic test data. The program first divides the ability scale into 12 equal intervals between ability scores of -3.0 and 3.0, and then calculates the expected p-values at each ability level and for each item using the three parameters of the logistic model. Residuals are computed by subtracting these estimated p-values from the observed p-values. The average residual for the entire test is -0.018, which suggests that the model predicted a slightly easier test than was experienced by this group. The average absolute residual is 0.067. Both values indicate a relatively close fit of model to data. Since the program also computes these residuals for each item and ability level, further study indicates which items and abilities are best accounted for by the model. The weighted average residuals for all of the items appeared similar (within 0.05 of each other), and mostly <0.02 in absolute weighted average residuals, indicating that the model fit the individual items well. The smallest

residuals appeared in the ability levels from -0.25 to 1.25. Apparently the model fits the data best at the ability levels which are slightly higher than average. This is useful since the test is being used to measure minimum competency for placement. Students with low ability will need the lower level remedial course certainly, while students of very high ability will test into the higher level course. The difficult decisions will occur with students somewhere in the upper middle group; precisely the ability level best predicted by the model.

Analysis Of Two Misconception Items

To illustrate the problems associated with using MIs in a multiple-choice format two exemplary MIs were selected from the present test. Items #9 and #20 contain misconceptions within their distractor choices. The misconceptions in both items appear in previous research.

Item #20 (see Appendix 1) contains a misconception concerning the concept of variable (Rosnick, 1981). The misconception is referred to as the reversal error since the most commonly chosen answer [even when not appearing in a multiple-choice format] involves an equation whose coefficients are reversed from the correct order. In item #20 the correct response is "d", $5C=W$. However, only 19% of the examinees responded correctly, while 46% selected distractor "b", $5W=C$. Although the item/test point biserial is 0.26, which is about two-thirds of the average item/test point biserial, the distractor/test point biserial for option "b" is 0.04. The distractor with the misconception correlates poorly with the rest of the test because it attracted so many of the high scoring examinees. These item statistics would suggest that to achieve higher test reliability the item or the distractor should be removed from the test. But research suggests that misconceptions with the concept of variable are best diagnosed with precisely this type of item. Classical Test Theory can be

viewed as placing a barrier between cognitive process research and standardized testing.

Item Response Theory can aid the test constructor in analyzing a test incorporating MIs by providing another perspective on item characteristics. The graph appearing in figure 2 illustrates an item characteristic curve for item #20. The slope of the line at the point of inflection is determined by the a-parameter, 1.05, which indicates a well discriminating item, especially among higher-ability examinees, as given by the b-parameter, 2.24. Although CTT indicates the relative difficulty of this item (low p-value), the low item/test point biserial would indicate that the item is a poor discriminator, IRT yields a very different interpretation.

The lower asymptote is given by the c-parameter, and is 0.12, which indicates that the probability of the lower ability students getting the item correct (probably by guessing) is less than 0.2 which is the probability of a randomly chosen correct response. One hypothesis for this behavior is that the misconception-distractor is not only attractive to mid and higher ability students, it is also extremely attractive to low and lower ability students. An examination of the matrix of responses by quintiles in MERMAC confirms this hypothesis: 50% of the examinees in the fourth quintile selected distractor "b", while 39% of the examinees in the fifth, and lowest quintile, selected distractor "b". It should also be noted that the residual analysis of the logistic test data showed the compatibility of model to empirical data higher for item #20 than most of the other items. The average absolute residual for item #20 is 0.033, while the average for the test was 0.067. IRT can predict performance on this item for any ability examinee with a high degree of accuracy. Furthermore, the item is useful in that it discriminates well among examinees.

Item #9 is a MI with similar item characteristics as item #20 although the misconception is quite different.

Item #9 (see Appendix 1) contains a misconception in distractor "b" which identifies a part/whole confusion in fractions concepts, (Benander & Clement, 1985). Instead of taking a "third of the remainder", many students simply take a third of the whole. Some students will misread the problem by deleting the phrase "of the remainder" even after they've been asked to reread the problem for accuracy. Apparently the misconception is so strong as to cause the student to read information into, or in this case, out of, the problem.

The CTT analysis is very similar to the analysis of item #20. Only 19% of the examinees scored item #9 correctly. The correlation with the rest of the test is 0.34, which is close to the average item/test correlation. Distractor "b", which contains the misconception, attracted 47% of the examinees, and correlated near zero with the rest of the test ($r_{pb1} = -0.05$). As in item #20, this item or its misconception-distractor should be removed from the test to improve the test's overall reliability.

Again, as in item #20, the IRT parameters indicate that this item discriminates well ($a = 1.797$), especially among higher ability examinees ($b = 1.81$). There is also less guessing on this item ($c = 0.11$). According to IRT this item can remain in the test since it contributes to the overall determination of examinee ability in an area that the test constructors wish to measure.

Conclusion

The inclusion of MIs in standardized multiple-choice mathematics exams can aid in identifying students who have a weak or confused understanding of certain concepts. The use of MIs is problematic since the standard analysis of items using Classical Test Theory indicates that by discarding the item or the distractor containing the misconception the reliability of the test is improved. This is due to low p-values, low item/test correlations and misconception-

distractors which attract even the higher ability students. Unfortunately, discarding the MI would amount to a trade-off of validity for reliability.

Item analyses using Item Response Theory aids the test constructor enormously. Not only are MIs acceptable, but they are statistically good items. IRT indicates that MIs discriminate well among examinees, especially higher ability examinees. IRT also gives the probability of a correct response to an item for an examinee of any ability. The item-characteristic curves illustrate graphically how the different items differentiate among examinees of varying abilities. Perhaps most importantly the IRT item parameters are independent of the group tested, a characteristic that is certainly not true of CTT statistics.

It is suggested that test constructors of standardized mathematics tests incorporate misconceptions into their items to test for conceptual understanding and that both CTT and IRT are used in their analysis.

Math Diagnostic Test

Please fill in the appropriate space on your answer sheet.
Do not write on this test. Scrap paper will be provided.

- 1) $\frac{5}{6} + \frac{1}{4}$
- a. $\frac{6}{10}$ b. $\frac{7}{12}$ c. $1\frac{1}{12}$ d. $\frac{13}{24}$ e. None of the above
- 2) $2\frac{1}{4} \times \frac{8}{15}$
- a. $1\frac{1}{5}$ b. $2\frac{8}{60}$ c. $2\frac{2}{15}$ d. $4\frac{7}{32}$ e. None of the above
- 3) $3\frac{3}{4} \div \frac{2}{5}$
- a. $2\frac{1}{4}$ b. $\frac{4}{25}$ c. $3\frac{1}{20}$ d. $\frac{4}{9}$ e. None of the above
- 4) Convert $5/8$ to a decimal.
- a. .5 b. .625 c. 1.6 d. .58 e. None of the above
- 5) Convert .7 to a percent.
- a. 70% b. 7% c. .7% d. .07% e. None of the above
- 6) Add $.06 + 4 + 3.8$
- a. 8.4 b. 7.86 c. 7.8 d. 4.8 e. None of the above
- 7) Divide .048 by 2.4
- a. .002 b. .05 c. .02 d. .005 e. None of the above

- 8) What is 20% of 7.5?

a. 1.5 b. 15 c. 3.75 d. 37.5 e. None of the above

- 9) Four people share a pizza in the following way: Tom got a third and Mary got a third of the remainder while Dick and Harry shared equally what Tom and Mary did not get. What fraction of the whole pizza did Harry receive?

a. $\frac{1}{3}$ b. $\frac{1}{6}$ c. $\frac{2}{9}$ d. $\frac{1}{4}$ e. $\frac{3}{2}$

- 10) A bicycle that regularly costs \$360 is on sale for \$306. By what percent has the price been reduced?

a. 10% b. 11% c. 6% d. 54% e. 15%

Evaluate the following expressions, when $x = -2$:

- 11) $x - 2(3 - x) - x(x - 5)$

a. 6 b. 0 c. 4 d. -26 e. None of the above

- 12) 5^x

a. -25 b. $\frac{1}{25}$ c. -10 d. 25 e. None of the above

- 13) $5 - 3 + 2 - x \div 2$

a. 18 b. 21 c. $9\frac{1}{2}$ d. $7\frac{1}{2}$ e. $8\frac{1}{2}$

- 14) $\frac{1}{2} \div \frac{1}{x} + 3$

a. 3 b. 4 c. 2 d. -1 e. $-\frac{1}{2}$

- 15) Calculate the outside surface area of a hollow tube:



- a. 12.5 feet
b. 150 square inches
c. 50 inches
d. 471 square inches
e. 75 inches

Write the following numbers in scientific notations:

- 16) 3,583,000

- a. 3.5×10^6 b. 3.58 c. 3.583×10^3 d. 3.583×10^6
e. 3583×10^3

- 17) .00004

- a. $.4^5$ b. 4×10^{-5} c. .04 d. $.4 \times 10^{-4}$
e. None of the above

Solve the following equations (find the solution set):

- 18)
- $2(5 - t) + 6t = t + 22$

- a. 6 b. $\frac{32}{5}$ c. 3 d. $\frac{12}{5}$ e. None of the above

- 19)
- $\frac{4t}{10} = 2t + 2$

- a. $-\frac{5}{4}$ b. 10 c. $-\frac{1}{8}$ d. -8 e. None of the above

- 20) For every person who orders chocolate milk, five order white milk. Write an equation which shows the relationship between "C", the number of people who order chocolate milk, and "W" the number of people who order white milk.

- a. $5W + C = 6$ b. $5W = C$ c. $\frac{C}{5W}$ d. $5C = W$ e. $C + W = 6$

- 21) What day precedes the day after tomorrow if four days ago was two days after Wednesday?

- a. Tuesday b. Wednesday c. Thursday d. Sunday
e. None of the above

- 22) A recipe for Crisp Crackers:

 $1\frac{1}{2}$ cups wheat flour $\frac{1}{4}$ cup seeds (sesame or caraway) $\frac{1}{4}$ cup peanut oil $\frac{3}{4}$ teaspoon salt $\frac{1}{2}$ cup water

If all I have is 1 cup of wheat flour, how much salt should I use?

- a. 1 teaspoon b. $\frac{3}{4}$ teaspoon c. $\frac{1}{2}$ teaspoon
d. $\frac{2}{3}$ teaspoon e. $\frac{1}{4}$ teaspoon

- 23) How many jars of water are needed to fill a
- $23\frac{1}{2}$
- liter jug if each jar contains 0.4 liters?

- a. $0.4(23.5)$ b. $23.5 - 0.4$ c. $\frac{2}{5}(\frac{47}{2})$ d. $\frac{2}{5}(\frac{2}{47})$ e. $\frac{5}{2}(\frac{47}{2})$

- 24) All items in a store are discounted 20%. Identify the expression which will calculate the sale price of an item.

- a. 20P b. $0.2P$ c. $\frac{4}{5}P$ d. $P - 20$ e. 120P

- 25) A bathtub can hold 124 liters of water. $\frac{1}{4}$ of the tub was filled in 20 minutes with the faucet turned on. How much longer will it take to fill the tub completely?

a. $\frac{3}{4}$ of an hour b. 40 minutes c. 80 minutes d. 1 hour

e. none of the above

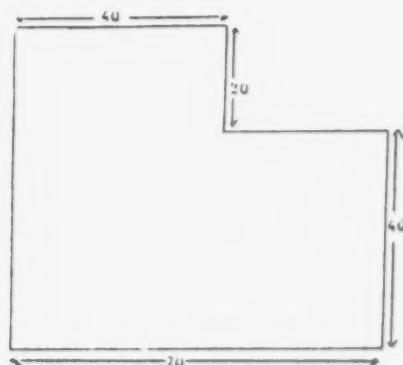
- 26) How many millions are in 1.8 billion?

a. 18 b. 1,800 c. 18,000 d. 1.8 e. 0.18

- 27) Which number is closest to $\frac{3}{100}$?

a. One Third b. 1.003 c. 3.100 d. 0.103 e. 0.031

- 28) What is the perimeter of the right-angled place figure below? All measurements are in inches.



- a. 260
b. 230
c. 200
d. 170
e. None of the Above

Summary of Test Statistics

Number of Items	28
Mean Score	12.01
Median Score	11.74
Standard Deviation	4.82
Reliability (KR-20)	0.777
S.E. of Measurement	2.28
Possible Low Score	0
Possible High Score	28
Obtained Low Score	0
Obtained High Score	26
Number of Scores	618
Blank Scores	0
Invalid Scores	0
Valid Scores	618

APPENDIX 3

Item	Distractors						IRT parameters		
	A	B	C	D	E	Omit	A	B	C
1 Prop	0.17	0.02	(0.63)	0.05	0.13	0.01	0.82	-0.12	0.20
RPBI	-0.38	-0.11	(0.45)	-0.14	-0.04	-0.22			
2 Prop	(0.52)	0.13	0.08	0.06	0.18	0.03	1.01	0.43	0.20
RPBI	(0.49)	-0.31	-0.15	-0.08	-0.12	-0.22			
3 Prop	0.05	0.04	0.10	0.05	(0.68)	0.08	0.99	-0.29	0.20
RPBI	-0.16	-0.13	-0.16	-0.12	(0.44)	-0.27			
4 Prop	0.03	(0.67)	0.08	0.11	0.06	0.06	1.24	-0.25	0.20
RPBI	-0.14	(0.53)	-0.20	-0.26	-0.14	-0.27			
5 Prop	(0.54)	0.19	0.06	0.17	0.02	0.01	0.98	0.42	0.20
RPBI	(0.48)	-0.20	-0.13	-0.26	-0.05	-0.20			
6 Prop	0.02	(0.88)	0.00	0.02	0.07	0.01	0.64	-2.79	0.20
RPBI	-0.05	(0.36)	-0.06	-0.17	-0.27	-0.20			
7 Prop	0.12	0.04	(0.69)	0.03	0.09	0.03	0.23	-1.36	0.20
RPBI	-0.09	-0.15	(0.29)	-0.04	-0.11	-0.22			
8 Prop	(0.63)	0.08	0.10	0.06	0.08	0.05	0.62	-0.19	0.20
RPBI	(0.35)	-0.07	-0.16	-0.08	-0.10	-0.26			
9 Prop	0.11	0.47	(0.19)	0.14	0.04	0.05	1.80	1.81	0.11
RPBI	-0.13	-0.05	(0.34)	-0.04	-0.11	-0.14			
10 Prop	0.09	0.09	0.15	0.04	(0.57)	0.06	0.57	0.13	0.20
RPBI	-0.14	-0.06	-0.16	-0.14	(0.36)	-0.14			
11 Prop	0.12	0.07	0.05	(0.28)	0.41	0.07	1.13	1.47	0.20
RPBI	-0.03	-0.08	-0.10	(0.38)	-0.12	-0.23			
12 Prop	0.28	(0.22)	0.05	0.29	0.12	0.04	1.78	1.61	0.12
RPBI	-0.07	(0.40)	-0.17	-0.09	-0.04	-0.24			
13 Prop	(0.37)	0.05	0.25	0.15	0.10	0.08	0.86	1.50	0.20
RPBI	(0.40)	-0.08	-0.03	-0.21	-0.11	-0.20			
14 Prop	0.20	0.18	(0.41)	0.08	0.04	0.08	1.17	0.89	0.20
RPBI	-0.16	-0.12	(0.44)	-0.07	-0.09	-0.24			
15 Prop	0.04	0.55	0.11	(0.13)	0.06	0.11	1.32	1.73	0.10
RPBI	0.04	-0.06	-0.17	(0.31)	-0.04	-0.07			

Item Distractors IRT parameters

	A	B	C	D	E	Omit	A	B	C
16 Prop	0.08	0.02	0.21	(0.34)	0.30	0.06	1.51	1.13	0.20
RPBI	0.01	-0.14	-0.21	(0.48)	-0.13	-0.30			
17 Prop	0.09	(0.43)	0.01	0.29	0.13	0.05	0.93	0.93	0.20
RPBI	-0.17	(0.45)	-0.08	-0.13	-0.12	-0.29			
18 Prop	0.04	0.06	0.09	0.09	(0.61)	0.10	0.46	-0.08	0.20
RPBI	-0.08	-0.13	-0.13	-0.07	(0.40)	-0.30			
19 Prop	(0.22)	0.17	0.12	0.07	0.24	0.19	1.68	1.56	0.15
RPBI	(0.38)	0.00	-0.07	-0.02	-0.08	-0.24			
20 Prop	0.11	0.46	0.16	(0.19)	0.05	0.04	1.05	2.24	0.12
RPBI	-0.10	0.04	-0.10	(0.26)	-0.07	-0.21			
21 Prop	0.12	(0.32)	0.25	0.13	0.13	0.05	0.55	2.06	0.20
RPBI	-0.04	(0.27)	-0.01	-0.14	-0.11	-0.12			
22 Prop	0.02	0.03	(0.40)	0.17	0.31	0.07	0.75	1.11	0.20
RPBI	-0.11	-0.05	(0.28)	-0.12	-0.06	-0.16			
23 Prop	0.30	0.10	0.17	0.11	(0.14)	0.17	2.00*	1.59	0.11
RPBI	-0.05	-0.16	-0.01	0.10	(0.33)	-0.20			
24 Prop	0.11	0.45	(0.24)	0.10	0.01	0.09	1.54	1.65	0.19
RPBI	-0.13	0.15	(0.25)	-0.24	-0.09	-0.21			
25 Prop	0.06	0.05	0.23	(0.47)	0.11	0.09	0.37	1.05	0.20
RPBI	-0.08	-0.08	-0.03	(0.27)	-0.11	-0.17			
26 Prop	0.21	(0.40)	0.14	0.06	0.07	0.13	0.75	0.90	0.20
RPBI	-0.03	(0.31)	-0.08	-0.13	-0.11	-0.16			
27 Prop	0.11	0.09	0.11	0.06	(0.53)	0.10	1.30	0.24	0.20
RPBI	-0.16	-0.13	-0.25	-0.09	(0.50)	-0.21			
28 Prop	(0.30)	0.31	0.02	0.09	0.17	0.11	1.10	1.56	0.20
RPBI	(0.33)	0.04	-0.06	-0.14	-0.13	-0.22			

- Allen, M. & Yen, W. (1979). Introduction to measurement theory. Monterey, CA: Brooks/Cole Publishing Co.
- Anastasi, A. (1986). Evolving concepts of test validation. American Review of Psychology, 37, 1 - 15.
- Benander, L., & Clement, J. (1985). Catalogue of error patterns described in courses of basic mathematics. Working Paper, Cognitive Processes Research Group, University of Massachusetts/Amherst.
- Berk, R. (1986). Minimum competency testing: Status and potential. In Flake, P., & Witt, J. (Eds.), The future of testing. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Birnbaum, A. (1957). Efficient design and use of tests of a mental ability for various decision making problems. Series Report #58-16, Project #7755-23, USAF School of Aviation Medicine, Randolph Air Force Base, Texas.
- Birnbaum, A. (1958 a). On the estimation of mental ability. Series report #15, Project # 7755-23, USAF School of Aviation Medicine, Randolph Air Force Base, Texas.
- Birnbaum, A. (1958 b). Further considerations of efficiency in tests of a mental ability. Technical report #17, project #7755-23, USAF School of Aviation Medicine, Randolph Air Force Base, Texas.
- Birnbaum, A. (1968). Some latent trait models and their use in inferring an examinee's ability. In Lord, F. & Novick, M. (Eds.), Statistical theories of mental test scores. Reading, MA: Addison-Wesley.
- Bussel, R., Costa, I., Spencer, R., & Aleamoni, L. (1971). Mermac manual. Urbana, IL: University of Illinois Press.
- Clement, J. (1982). Algebraic word problem solutions: Thought processes underlying a common misconception. Journal of Research in Mathematics Education, 13(1), 16 - 30.
- Fredette, N., & Lochhead, J. (1980). The Physics Teacher.
- Hambleton, R. (Ed.), (1983). Applications of item response theory. Vancouver, BC: Educational Research Institute of British Columbia.
- Hambleton, R., & Murray, L. (1983). Some goodness of fit investigations for item response models. In Hambleton, R. (Ed.), Applications of item response theory. Vancouver, BC: Educational Research Institute of British Columbia.
- Hambleton, R. & Swaminathan, H. (1985). Item response theory. Hingham, MA: Kluwer-Nijhoff Publishing Co.
- Henryssen, S. (1971). Gathering, analyzing, and using data on test items. In Thorndike, R. (Ed.), Educational Measurement, 2nd ed. Washington, DC: American Council on Education.
- Leinwand, S. J. (1983). Tests and texts: An application of the conference board report to the NSB commission on precollege education, or the frustrations of an unabashedly optimistic math consultant. Hartford, CT: State Department of Education.
- Lord, F.M. (1952). A theory of test scores. Psychometric Monograph, No.7.
- Lord, F. M. (1953 a). An application of confidence intervals and of maximum likelihood to the estimation of an examinee's ability. Psychometrika, 18, 57 - 75.
- Lord, F. M. (1953 b). The relation of test score to the trait underlying the test. Educational and Psychological Measurement, 13, 517 - 548.
- Lord, F. M. (1974). Individualized testing and item characteristic curve theory. In Krantz, D., Atkinson, R., Luce, R., & Suppes, P. (Eds.), Contemporary developments in mathematical psychology, Vol. II. San Francisco, CA: Freeman.
- Minstrell, J. & Stimpson, G. (1986). Students' beliefs in mechanics. Proceedings of the fifth conference on reasoning and higher education, Boise State University.
- Rosnick, P. (1981). Some misconceptions concerning the concept of variable. The Mathematics Teacher, 74(6), 418 - 421.
- Tinkelman, S. (1971). Planning the objective test. In Thorndike, R (Ed.), Educational measurement (2nd ed.). Washington, DC: American Council on Education.
- Wingersky, M. (1983). LOGIST: A program for computing maximum likelihood procedures for logistic test models. In Hambleton, R. (Ed.), Applications of item response theory. Vancouver, BC: Educational Research Institute of British Columbia.

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1. INTRODUCTION

Our approach to research and improvement of physics teaching on the high school level is centered around three aspects:

- (1) Our own investigations since 1970 (e.g. Niedderer, 1972) as well as the work of many other authors all over the world (cf. Duit 1985, Frey 1984, Helm 1983, Pfund 1987) seem to converge in building up a strong paradigm for research in science education: Learning processes are based on students' frameworks and conceptions. Therefore it is necessary to investigate how students get their conceptions about physical phenomena and issues. Correspondingly, our first aim is to investigate the students' "matrix of understanding" (see below) in various thematic fields (mechanics, atom physics) of high school and college physics.
- (2) Starting from a teaching project "Theory of Science and Physics Teaching", we have tried to apply the results of the so-called "New Philosophy of Science" (Lakatos, Kuhn, Feyerabend, Toulmin et al.: cf. Brown 1977) to our research of science teaching. This resulted in defining the concept "matrix of understanding" (which is to be described below). We are convinced that the process of learning is determined for each student by this "matrix of understanding". From this hypothesis we have developed a new approach to physics teaching which centers around students' questions, expectations and ideas ("Schülerverständnis orientierter Physikunterricht" - SVU). This view of physics teaching is similar to that of R.Driver, R.Osborne and others. An additional aim of this kind of teaching is to give a more realistic picture of physics to the students. In two investigations of our group, Baumgart, Krüger and Schecker evaluated that teachers and students mostly have a naive-empiristic view of methods and results in physics. (Krüger 1982). In the course of discussing concepts, experiments and phenomena we therefore put in information

about the historical background and show parallels between historical issues and students' interpretations.

- (3) It is our conviction that there has to be a connection between research in science education and the development of new learning materials for students and teachers. We do not develop complete curricula (as we did in the early 70s), but special units in addition to current physics teaching. For these purposes we cooperate with about 20 physics teachers whom we supply with teaching materials, historical texts, new experiments and interesting issues for discussion. They give us the opportunity to gain information from their physics courses through tests, interviews with their students and recordings of lessons.

2. THE CONCEPT "MATRIX OF UNDERSTANDING"

From works of Kuhn (1976), Lakatos (1974), Holzkamp (1968) and others we have learned that the process of knowing in physics is determined by belief systems concerning relevant subject matters, goals and methods which guide the acts of discovery (e.g. in experiments). While Kuhn speaks of "paradigms" or "disciplinary matrices" and Lakatos of "research programs" - concepts aiming at scientific communities - we call the respective ensemble of cognitive guidelines referring to an individual person in an act of discovery the "individual matrix of understanding" (cf. Niedderer 1975, Redeker 1981, Niedderer 1982b). An individual matrix of understanding is the corpus of all dispositions that influence the way a person deals with a certain group of phenomena or problems. When students are confronted with a problem, certain dispositions from this set are activated and influence observations, ideas, descriptions, tentative explanations or the formulation of findings.

An individual matrix of understanding consists of two main groups of elements:

1. General elements (relevant in more or less all fields of physics teaching):
 - general interests and frameworks (basic characteristics of approaching physical phenomena)

- ideas about subject matters, goals and methods of physics (epistemological ideas)

2. Specific elements (relevant in special subjects, e.g. mechanics or atomic physics):

- interests in special subjects
- preconcepts about particular scientific terms, principles, laws
- specific knowledge and experiences.

These two groups are intertwined as will be shown in the following examples.

The matrix of understanding (MOU) is a hypothetical construct. Its postulation can be justified by showing it to be a valid instrument for interpreting and understanding students' behaviour, especially their difficulties in learning.

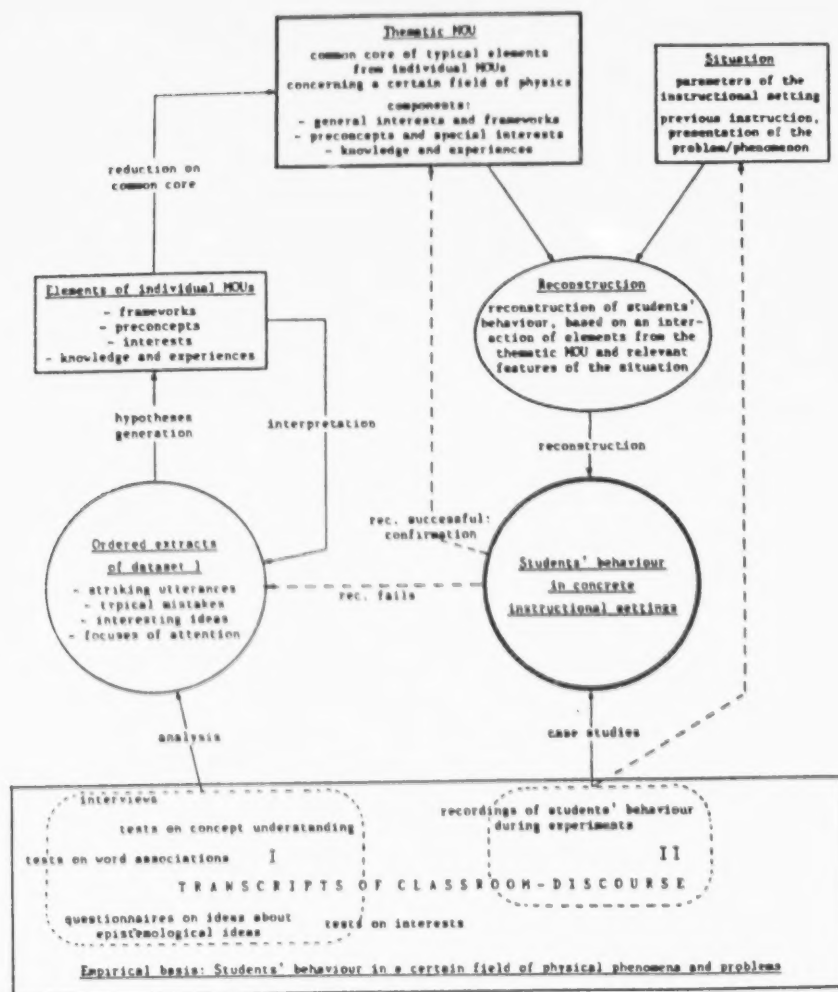
The sets of elements from individual MOUs among a sufficiently homogeneous population (same age group and comparable amount of physics instruction) can be reduced to a limited core of typical broad-based elements. The aim of this reduction is to make the spectrum of MOUs more comprehensible and provide teachers with a manageable collection of central frameworks, preconcepts and interests. We call the common core of comprehension-guiding elements in a certain field of physics the "thematic MOU". It can be structured in the same way as an individual MOU (see above).

3. RESEARCH PROGRAM

The goal of our research program - which is described and applied in detail in Schecker (1985) - is to develop thematic MOUs e.g. in mechanics and atomic physics that enable us to understand, i.e. to reconstruct the behaviour of students in concrete instructional settings. Empirical data about the way students react to the presentation of certain physical phenomena and issues form the basis of our research program.

This research program contains several qualitative and quantitative methods (see below). The findings of these investigations are related to specific hypothetical elements of the matrix of understanding (MOU) to supply arguments for agreement or disagreement with those hypotheses. The whole process is based on systematical interpretation rather than classical, empirical calculations. The process typically goes through 6 stages (see also Fig.1):

1. Gaining a first empirical basis from interviews, questionnaires and audio-recordings of physics lessons (Dataset I).
One of the main tasks in this stage is to transcribe classroom-dialogues: What do students actually say and do in physics courses (high school level)?
2. Collecting, arranging and presenting the students' typical statements, questions, ideas, mistakes, difficulties. (Ordered extracts from Dataset I).
3. Making hypotheses about elements of individual MOUs that can explain the documented behaviour. Relating behaviour in specific situations to more general cognitive structures.
The generation of those hypotheses is related to discussions about new ideas in physics teaching (see below) and thus this process is connecting empirical research to those ideas of improvement.
4. Forming the common core of elements that have proved to be important for interpreting students' behaviour: Thematic MOU.
5. Expanding the empirical basis, preferably by new recordings of physics lessons (Dataset II).
6. Testing the postulated thematic MOU on its capacity to reconstruct comprehensively students' actual behaviour by an interaction with the respective situational settings. (Examples are taken from the new Dataset II).



I : dataset I
II : dataset II

Fig.1

4. METHODS OF OUR EMPIRICAL RESEARCH

4.1 General Idea

A lot of researchers in the field of empirical studies have made the following experience: You have done substantial work with a lot of data but the results do not mean very much in practice. To overcome this problem we try to apply the following principles:

- Generate hypotheses on the basis of theoretical discussions about the improvement of physics teaching and on qualitative data gained in physics lessons
- combine qualitative methods (recordings of classroom lessons, interviews) with quantitative methods (questionnaires, tests) to get data that are related to those hypotheses (to give evidence for or against a hypothesis 1).

Our background perspective for generating hypotheses can be summarized in four aspects:

- (1) Our view is strongly influenced by the "new philosophy of science". It follows that we are interested in the students' philosophy of science with respect to their ideas of the relation between theory and experiment, their expectations of aims in physics, their general way of dealing with concepts (compared with ways in everyday life or technique or physics).
- (2) We consider the learning of science to be a generative process (Osborne 1983b, Wolze 1986). We think this is similar to the so-called "constructivist view of learning" (Kelly 1955, Strike 1982). That means we are interested in students' tools of scientific work and their metatheoretical conceptions, e.g. methods they prefer in their own working process (e.g. working with formula, taking empirical data, discussion about analogies, etc.)
- (3) We have developed and tested in practical physics teaching a new teaching strategy (cf. Niedderer 1987) which is strongly related to students' own questions and ideas, their own work and their own formulations of results. Therefore we look for students' interests, their associations and questions.
- (4) We take the physicist's formulations of concepts, principles and laws as the basis against which we compare the students' alternative views and their conceptions.

4.2 Single Qualitative Methods

(1) Audio-recordings of physics lessons. This is our main method of gaining data. We take audio-recordings of physics lessons, which are then transcribed and put into a process of interpretation (see Fig.1 above). This method guarantees that our results relate to practical teaching situations. The material is especially useful, when teachers allow for the discussion among students.

(2) Open experimental interview (cf. Bormann 1987). This method is a kind of clinical interview like Piaget's. It typically starts with a first experiment (e.g. Hallwachs effect, electron diffraction tube), which is carried out by the interviewer without any (physical) explanation. The students (typically three students in one group) are asked to write down their first explanations on a sheet of paper. This gives us data for further evaluation. Each student has to find his own first view before discussing it with one another. The students are then invited to discuss the experiment, to ask questions and to make proposals for additional experiments. This altogether is called stage one. It can last from thirty minutes to one and a half hours.

The whole interview has got two to four stages. A new stage is started by the interviewer with a new, short piece of information (e.g. a new experiment or a theoretical hint or a short passage from a textbook or a historical paper).

(3) Other additional interviews during group work in lessons or after filling in a questionnaire.

4.3 Single Quantitative Methods

(1) Questionnaires with thinking-type questions. Those questions are different from ordinary questions in lessons. Hardly any calculations are necessary, but the students need a qualitative understanding of the underlying concepts and laws. Example (Schecker 1985, p.113):

An ivory ball is being shot from a catapult and bounces against a steel block in a distance of about 1m.

This experiment is set up on a billiard table. Fig.2 shows some action shots during the experiment.

Put a v-t diagram into the coordinate system to show the process of the experiment.

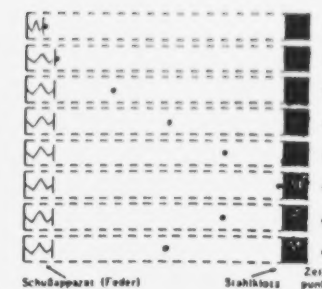
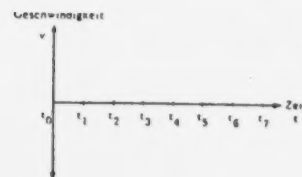


Fig.2: Trajectory of the ball seen from above

(2) Tests asking for associations or a definition of a single word or concept, e.g. force, energy, atom, energy level.

(3) Tests on interests. A set of statements like "To measure the speed of a moving car" are to be scaled from 1 (I don't like this at all) to 5 (I should like this very much).

(4) Questionnaires with open answers where students are asked to describe their views of certain aims and methods of physics.

5. RESULTS ON ALTERNATIVE FRAMEWORK OF STUDENTS

As discussed above we apply the concept "matrix of understanding (MOU)" to structure the findings and hypotheses about students' alternative frameworks. In the following I shall present some results in reference to the four aspects of our background perspective listed above:

- (1) Elements of the MOU describing the students' philosophy of science (see 5.1).
- (2) Alternative metatheoretical conceptions (see 5.2).
- (3) Interests of students (see 5.3).
- (4) Students' alternative concepts in physics (see 5.4).

5.1 Elements of the MOU Describing the Students' Philosophy in Science
First, I discuss a general difference between theories in science and "theories" in everyday life: Science is aimed at general theories and

general concepts, useful in a variety of situations, whereas descriptions in everyday life are always related to single specific situations (cf. Böhme 1981, Redeker 1978). This has consequences in subject matter ideas as well as in interests and in the concept formation by students.

In relation to this result of science philosophy Schecker (1985) found several elements of the MOU (EM) which will be described now with selected examples for evidence.

EM 1: The Task of Physics (subject matter)

Students think physics should investigate specific single problems of everyday life with sophisticated methods.

Example 1: The following two items were part of a questionnaire "conceptions about philosophy of science" (N = 449).

A1) Physicists have to investigate processes we meet in everyday life more exactly, more systematically and more sophisticated than "normal people" can do.

A5) The aim of physics is to find general concepts. Physics is not so much interested in special results for specific problems.

Results:	A1 :	+ 91%	- 4%	? 4%
	A5 :	+ 19%	- 62%	? 19%

+: agreement, -: disagreement, ?: no answer (Schecker 1985, p.160).

This means that students tend to agree with statement A1. For them specific results in single problems are more important in physics than general concepts.

Example 2: From an open question in the same questionnaire Schecker comes to the following types of students' arguments for the relevance of physics:

- In everyday life we use concepts which are defined by physics. "We need physics to compute the velocity of people, of a car, a train, etc."
- Phenomena of everyday life are explained by physics: "Physics explains why you tend to fall forward if the train stops".

- Physics explains how technical machines work: "Today physics is everywhere, in cars, rockets, weather, airplanes, etc."

In all these types of answers students see physics in connection with single specific problems or technical machines. Students reply strongly to the capability of physics to be helpful in everyday life. Sometimes this is combined with complaints on physics teaching: "Such things (single problems) are too seldom taken up in physics teaching. Mostly we learn something about "physics" and we don't know why. That is not interesting".

EM 2: Students tend to solve theoretical and abstract problems by transforming them into concrete situations of the real world.

Example 3: A working paper for university students (first semester) contained the following question:

"A ball is rolling down an inclined plane and immediately afterwards rolling up a similar inclined plane (no energy loss). Is this periodic movement a harmonic oscillation? Give $x(t)$, $v(t)$, and $a(t)$ in a graph!"

From 11 students 3 did not answer, because they said they did not understand the question. They had drawn the two planes correctly but they supposed that this could not be meant, because the ball would spring at the edge, that would cause an energy loss and that was excluded in the question! 2 students reformulated the problem: it should be a circular plane. 6 students worked on the problem in the "right" way, but two of them asked similar questions before (Schecker 1985, p.138).

This shows how students refuse an abstraction of a problem because they work with special concrete realizations in their minds. Their concrete realization "shows" them a picture of a jumping ball!

Other similar examples show how students can't "forget" friction because they use their concrete images of special processes in their environment. We have transcripts of classroom situations, where the teacher tries to idealize the motion of falling bodies in a horizontal motion with constant velocity and a vertical motion with con-

stant acceleration. Students don't grasp these ideas because they discuss in detail the influence of air friction on the velocity of special movements. Students in those cases often really don't understand what the teacher aims at.

But there are also students who distinguish between specified and generalized viewpoints in a discussion of a specific phenomenon: "If there is no resistance of air, the velocity will increase. It will become more and more infinite but it will never really reach infinity... If we take air resistance into account, we will definitely reach a maximum velocity".

A corollary to EM1 is EM3, formulated in terms of students' interests:

EM 3: Students are specially interested in specific phenomena (e.g. single experiments) whereas physics or physicists or physics teachers are interested in special phenomena only as examples for a general concept or theory.

Example 4: In a classroom situation students were allowed to state their own questions and hypotheses around the problem: What does acceleration depend on ($a = f(???)$) ? The students examined special cases of acceleration (a locomotive, a car on an inclined plane, a car accelerated by the wind of a hairdryer, etc.) and formulated corresponding questions inventing special forces for each example.

Other examples show that students are interested in solving single problems in all details. Students invest a lot of work in describing and investigating such details of a special experimental apparatus.

EM 4: Students are more interested in practical and technical problems than in the generalized structure of a phenomenon.

Example 5: In a thinking-type question students were asked to discuss the problem why a car may leave the road when driving round a curve. In spite of the explicit physics context of the item 30% of the students used only technical terms in the discussion of this problem. They discussed the influence of rain, ice, driving too fast, bad reaction of the driver. Only about 40% of the students

used a physical viewpoint I (Schecker 1985, p.231 ff).

Secondly I now discuss some elements of the students' MOU concerning the relation between experiment and theory. While an empiristic view tends to see theories develop from a logical analysis of primarily found experimental data, a rationalistic view says on the contrary, that experiments are "only" realizations (cf. Holzkamp 1968) of theories which were contrived before.

EM 5: Students tend to hold an empiristic view. They think that physics leads to unique theories which come out of exact and sophisticated experiments and measurements. The theoretical viewpoint at the beginning of an experiment is less important.

Evidence to this result is given by two earlier investigations in our group (Krüger 1982). He found that most students (about 70%) tend to hold an empiristic view (theories are verified by experiments, formulas give an objective description of nature, theoretical knowledge comes out of experiments, etc.) Schecker (1985) gives more examples from current physics teaching and a new questionnaire.

The elements EM 1 to EM 5 of the students' matrix of understanding (MOU) show parts of a picture of the students' philosophy of science. They show big differences between the viewpoint of physics and that of the students. While the first four elements are supposed to be due to everyday life thinking (aimed at specific situations and not at generalized concepts), the fifth element probably is a "result" of physics teaching itself: Teachers tend to spend very little time on reasoning about questions, hypotheses and theoretical background before starting an experiment. The observations and results from every experiment are given quickly and in a straight way (because of the lack of time).

5.2 Elements of the Students' MOU Describing Metatheoretical Conceptions

Schecker (1985) has found six elements: Thinking in properties, thinking in an activity-scheme (causality-thinking), thinking in purposes and

aims, thinking in analogies, using formulas as dominant language of physics, global thinking.

All these dimensions can be useful tools for the student to start developing own explanations, questions, theoretical backgrounds. They allow him to begin a process in which he activates his own thinking and this is the best for learning. Most of these elements have been found by many others, too. (cf. Jung 1981a).

5.3 Students' Interests, Especially in Mechanics

To allow for students' own activities to enable "learning as generative process" it is most relevant to know their interests as a kind of direction of motives. We already have described two interests above (EM 3 and EM 4), which are very important to find strategies for a generative process: Students should get the chance to work on a single phenomenon and it is useful, if there is a technical or practical component. As for mechanics, Schecker (1985, p.243 ff) has found a specific interest:

EM 6: Students prefer to discuss dynamic aspects of motion. Kinematic descriptions have less importance for them. They ask more questions about causes, forces and energy than about the functions $x(t)$, $v(t)$, $a(t)$.

Example 6: In a word association test on "motion" most associations (30%) came from acceleration and velocity. Force and energy had less than 20%. This result does not give evidence for EM 6. We still keep the hypotheses because of strong evidence from other sources.

Example 7: In several classroom dialogues Schecker (1985) shows, how teachers tend to consider primarily kinematic "descriptions" of movements (in the first part of a mechanics course), whereas students insist on discussing causes, forces and energy. Very often there are misunderstandings in these lessons.

Example 8: In a special teaching concept, students investigated with their own questions and own experiments the general problem: What are the conditions for acceleration ($a = f(???)$)? The high degree of student participation in this teaching process was due to the fact, that this activity - to find causes, forces, etc. - is the

main specific interest of students in this area (cf. Niedderer 1987).

5.4 Motion and Forces - Elements of the MOU in Mechanics

In accordance with international research on conceptual frameworks in mechanics (Arons 1981, Champagne 1980, Clement 1982, Jung 1981a/1981b, McCloskey 1983, Schenk 1983, Trowbridge 1981, Viennot 1979, Warren 1979, Watts 1983, Whitaker 1983) the findings of Schecker (1985) show strong common trends in the students' difficulties and their alternative conceptualisations of mechanical terms. The parallelism of these results justifies the effort of constructing the "matrix of understanding" (MOU) concerning mechanical phenomena and problems. We will here concentrate on elements that centre around the concept of "force". After describing central frameworks and precepts, an example taken from a lesson about the collision of bodies will illustrate the MOU's explanatory power.

The most relevant general finding is, that the concept "force" of students varies from one situation to the other. It has a special meaning in a specific single situation. On the other hand the concept "force" in physics has one general meaning for all situations. This is due to the same difference between physics and everyday life as discussed above in 5.1: Physics is aimed at general theories for a great variety of situations, whereas everyday life is only using statements about single specific situations. We call the corresponding type of concepts a "cluster concept".

For most students "force" is a cluster concept, even after being taught Newtonian Mechanics for weeks and months. Viennot (1979, p.208) calls it an "undifferentiated explanatory complex". The word "force" is used in a great variety of physically different meanings: Newtonian force, momentum, potential and kinetic energy, torque, time integral of force etc. Cluster-concepts like "force" or "heat" sharpen out their meanings in concrete communicative situations. Boehme (1981, p.94) speaks of "indexicality": terms in everyday language are vague in their general contents, but precise in contexts. Students know that it has different implications to speak of a fast moving body "having much force" or of a "force being exerted" upon a body.

It must be stressed that students do not simply take the same word to

denominate concepts that they implicitly distinguish. The cluster-concept "force" covers a wide field of phenomena and problems. "Force of motion", "force of impact", "accelerating force" are different modes of one universal explanatory scheme. They are considered to be essentially the same things. "Force of motion" can be changed into "force of impact" during a collision. The "force of the mover" is passed over to an object as "force of motion". Newtonian force as an outer accelerating influence on a body is just another facet. This does not mean that students do not make any distinctions at all. Most of them learn, for example, to associate the correct formulas needed to solve standard test items. But the distinction is not that between a relational concept "force" or "energy" or "momentum" as categories of a quantity type. "Force", "energy" or "momentum" are all three seen as interchangeable substances or properties of bodies. A student who was asked whether he found it necessary to discriminate between the three terms put it that way: "Well, of course it's necessary. After all they are different forces".

So Schecker (1985) comes to another element of the MOU specific for mechanics:

EM 7: Force is a general activity potential. Bodies in motion have (possess) force. A force is acting in the direction of motion. Motion occurs in the direction of the resultant of all acting forces.

The meaning of force has nothing to do with formulas (e.g. $F = m \cdot a$) which are only used for calculations. Especially force is not restricted to acceleration.

Force is a cluster-concept which gets its special meaning only in a specific context.

5.5 Interpretation of Students' Behaviour on the Basis of the MOU

The following example is taken from an A-level course in physics (students aged 16 to 17; six lessons a week). The preceding units dealt with kinetics and inelastic collisions. Subject of the present unit is "force". The students have learned about Newton's laws and the relation between force and momentum. A number of problems have been solved using the formulas " $F = m \cdot a$ " and " $\Delta p = F \cdot \Delta t$ ".

Teacher: I want to examine the relation between forces and momentum at the example of collisions. Let's take two cars that collide on a horizontal track. (T. draws a diagram). Well, they somehow collide with each other. Don't think about how they moved before. What can we say about the forces that are exerted?

Peter: Those which the two cars exert on each other during the experiment?

Teacher: Well, they have just started to collide. The spring has been compressed a bit. What can we say about the forces right at this moment?

While the teacher aims at the momentary magnitudes of the forces during the interaction ($F_{A \rightarrow B} = -F_{B \rightarrow A}$) Peter is probably thinking of "forces" "during the experiment", i.e. of "forces" that the cars "have" and that enable them to act upon each other. This point of view is obvious in the next statement:

Volker: Well, I see it that way: The spring stores up force for a moment. The spring is compressed. That means that it is acted upon in some way. And then the spring gives back this force.

Teacher: You've introduced an additional point: a force is necessary to compress the spring. But let's concentrate on the influence of car A on car B and vice versa. This is the important aspect for the behaviour of both cars.

Martin: The force of one car is passed over to the other. This happens on both sides. The force of car A is passed over to B and the force of B to A.

Teacher: Car A exerts a force on car B. This force can only be exerted in this direction (Teacher points from left to right). It is not important at the moment, how big the force actually is or how it changes during the collision. But how big is the force that is exerted by B on A?

Students: (no answer)

Teacher: This is a matter of action and reaction. How big is this second force?

We can clearly see, how teacher and students misunderstand each

other. They use "force" in completely different ways. When the teacher speaks of the force that B exerts on A, it is the reaction to $F_{A \rightarrow B}$. The students speculate about forces that the cars "have" because of their motion before the collision - forces that enable them to act upon each other and to compress the spring. These forces are exchanged between the cars after being stored intermediately in the spring. The students keep their sights on the transmission of "force".

Volker: Well, it's exactly the force that existed before. When A is standing before the collision and B has a velocity, then afterwards A moves on into the same direction with the same velocity as before car B.

Teacher: At the moment we are talking about forces at a certain point of time during the collision - not about what happens later. Let's imagine we could attach a force-meter to one car that shows us car A pushes against B with a certain force $F_{A \rightarrow B}$. With what force does B push against A then?

Arno: I should say it is just the other way round. That is the force F_B .

Teacher: That's just a name - how big is this force?

Arno: I should say, if this mechanical process is without friction, then the force should be the same.

Teacher: Yes, the same - but there is one difference ... (Teacher is interrupted).

It is not quite clear what Arno means. He may be reflecting upon a reaction force. But his last sentence casts some doubt upon this interpretation. "Friction" refers to the energy aspect of the cluster-concept "force": No "force" is lost during the collision. The teacher seems to believe that Arno is thinking of the "right" thing. His last remark is meant to hint at the direction of $F_{B \rightarrow A}$. But he is interrupted by Ingo.

Ingo: How can it be the same? If the forces were different before, then they can't be equal now.

Teacher: There seems to be a problem with this term "force". What do you mean by "the force that A had before"? This car is just moving along at a certain speed. Where shall there be

a force?

Ingo: The car must have its motion from somewhere, so that it started to move at all.

Ingo's statement shows the coupling of motion with "force". This "force" has been given to the car when it was set into motion. Students often consider the question, how a certain movement has come about, to be important for the description of its momentary state. Teacher and students go on discussing the problem of forces during a collision for thirty minutes. Although the teacher is insisting on it, only two students take over the aspect of interacting forces. The majority keep on talking about "the forces of the cars" and about "transmission of force". The restriction of force to a purely relational concept meets with strong opposition in the cluster-meaning of "force" as a property of bodies or a general "capacity for action". In the chosen lesson the communicative conflict lies at the surface. In many lessons mutual misunderstanding remains under the surface, because the students do not get the opportunity to express their real thoughts. Formal faculties to solve numerical problems often cover conceptual deficits.

6. PRELIMINARY RESULTS IN ATOMIC PHYSICS

There seem to be very few research activities in students' alternative framework in the field of atomic physics and especially quantum physics all over the world. (cf. Pfund, Duit 1987). This situation causes difficulties and uncertainties for the interpretation process. Therefore we tend to be more modest in our expectations of the results. At the present stage documenting observations and students' statements about concepts and theories is more important; the aim of formulating elements of the MOU is perhaps not attainable within the first step.

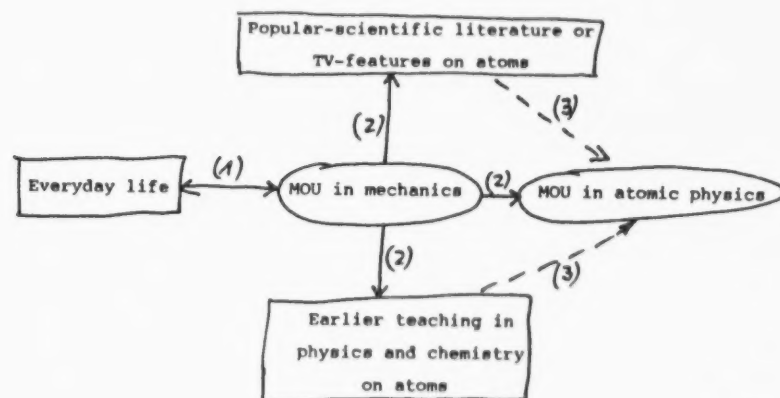
The following preliminary results are parts of the running doctoral theses of two members of my research group:

- Malte Bormann: Students' Alternative Framework in the Field of Particle and Wave Models of Light and Electrons (Bormann 1987)
- Thomas Bethge: Students' Alternative Frameworks in the Field of Bohr's and Schrödinger's Model of the Atom (Bethge 1987).

Some results are from a former co-worker in my group (Bayer 1986).

6.1 General Aspects

One reason for the scarcity of research work in this field is perhaps a different relation of atomic physics to everyday life which causes a different structure - perhaps a more variable one - of the MOU. In mechanics there are many associations to everyday language and to everyday actions. So we have to account for elaborated structures independent from physics teaching. One general hypothesis we follow in the field of atomic physics is that the students' alternative frameworks are mainly influenced by their MOU in mechanics. This is shown in the following diagram:



- (1) : Strong relations because of language, actions, communication, reality, etc.
- (2) : Parts of the thematic MOU in mechanics determine students' own thinking concerning atomic physics
- (3) : Specific parts of knowledge which are stable in memory, because they are in good accordance with parts of the MOU in mechanics.

This means that in a threefold way mechanical thinking can be expected to be dominant in students' thinking in atomic physics. Perhaps this is also an explanation for the preference of the Bohr model of the atom by students (and teachers as well).

We discuss a second general hypothesis: The elements of philosophy of science held by students in the field of atomic physics show some new aspects. For instance, we have observed that students seem to accept idealizations more easily. On the other hand many of the general elements of the MOU in mechanics can be found here, too: Thinking in analogies (for photon or electron); thinking in properties (light has colour; atoms bear the properties of solids); models are taken as reality and if there are more models, they are combined (assimilated). A special observation has been made in respect to formulas: the smaller number of formulas and of quantitative problems lead students to some doubt about the quality of these theories.

6.2 Particle-Wave Synthesis

The atomic physics course in grade 13 normally starts with light and electrons as particles and waves. The so-called "dualism" is

often connected with the notion, that electrons or light in one experiment are particles and in another experiment are waves. To avoid this unsatisfactory double-nature we give the students the idea that a new model called "quant" is needed which is a synthesis of both. This approach is likely to meet students' interests because they generally tend to combine different models to one (see above).

In three experimental interviews with

- the electron diffraction tube
- the double-slit experiment with electrons (demonstrated with pictures and diagrams) and
- The Ramsauer effect (pictures and diagrams)

Bormann (1987) investigated students' own efforts to find such a synthesis for the electron. Mainly he found three conceptions:

(1) The "strict" particle view

Students looked at electrons as particles moving along straight lines. The observations of electron distributions were explained by collisions.

(2) The particle moving along a wave

The electron is a particle (mass, velocity, orbit).

This particle moves along a wave-orbit. The electron is the oscillator of the wave.

(3) The formal wave conception

The diffraction pattern is explained by an electron wave. Either the electron is a wave itself or there is a new kind of wave (which is influenced by a magnetic field).

In addition Bormann works on the following hypotheses:

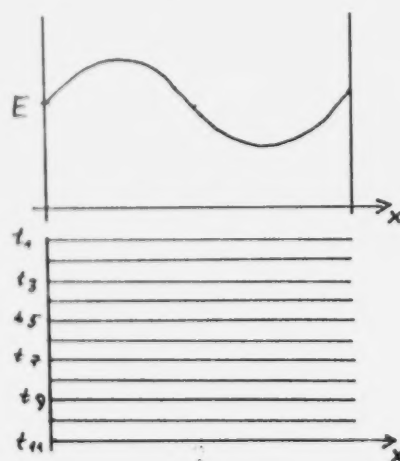
- The particle view is easier for students to understand than the wave view.
- The electron is a "real" particle, the photon is a sort of "energy particle".
- Photons and electrons are primarily particles which should have some wave properties to explain special sophisticated experiments.

6.3 Model of the Atom

Our course aims at a Schrödinger model of the atom which contains standing probability waves which give the probability density of the electron. Most teachers start with the Bohr model and then come - with more or less hesitation - to the wave model of the atom. We start with simple standing waves in simple potential wells and use computer simulations and mechanical models for explanations.

One thinking-type question of Bethge is the following:

The wave function of an electron in a potential well is given in the diagram. a) mark the possible place of the electron at different times in the diagram. b) Give a short explanation!

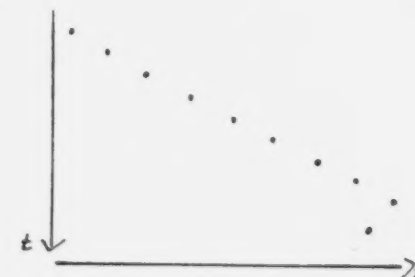


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Bethge found four types of diagrams at the end of the course ($N = 442$):

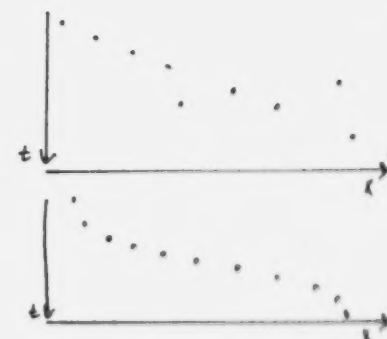
(1) The electron moving with constant velocity

45%



(2) Similar as (1), but with few statistic dates

15%



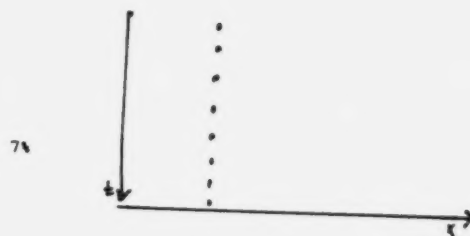
(3) The correct answer (maximum density at the maximum of the sine function)

25%



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(4) Always at the same position 7%



(5) No diagram 8%

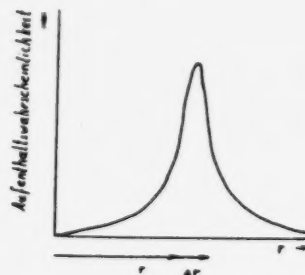
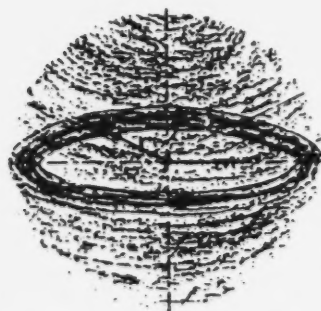
This result tells us: Most students think of electrons in a square well potential as moving like a classical particle with constant velocity from left to right and back again.

Some other preliminary statements are:

Electrons in the atom

- The atom is stable because of the motion of the electron
- Orbit and energy level have similar meaning ("state")
- The concept of orbit is mixed with the concept of probability density.

Students often come to a conception of "smeared" orbits (Bayer 1986):



- Electrons move along wave orbits around the nucleus (de Broglie's picture is often used by teachers).

Energy/Spectra/Energy level

- Discrete light spectra do not strike students as issues for closer examination
- The same goes for discrete energy levels: They are accepted as simple facts not worth further consideration.
- Students tend to use energy-conservation-thinking when discussing light absorption and similar problems. The energy concept is often used in "difficult" situations as a general activity source (compare 5.4).
- Light emission spectra are explained by absorption. Light cannot be "produced" by an atom, light is "everywhere", it can only be absorbed or changed by atoms.

Resonance

- The interaction of waves often is explained by resonance (e.g. photo effect, absorption of light, Ramsauer effect).

These preliminary results show difficulties for the learning process toward a wave model of the atom: mechanical thinking in orbits of classical particles is very dominant and tends to lead to misunderstandings of a quantum model. Perhaps there is one chance: That students construct a new model of the "quant" for themselves in a slow generative process, using parts of their own models of a particle and a wave, with many chances to bring forward own ideas of modeling the atom and comparing these own ideas with historical or modern views in science. It seems to be necessary to prepare such a course by an illustrative course on waves and especially standing waves in one, two and three dimensions using mechanical waves, sound waves and electromagnetic waves.

- Arons, A.B.: Thinking, Reasoning and Understanding in Introductory Physics Courses; in: *The Physics Teacher* 19 (1981), p.166-172
- Bayer, H.J.: Schölvorstellungen beim Übergang vom Bohr'schen zum wellenmechanischen Atommodell, in: Kuhn, W. (Ed.): *Didaktik der Physik, Vorträge, Physiker-tagung 1986 Gießen, Gießen 1986*
- Bethge, T.: Zum Verständnis zentraler Begriffe der Quantenmechanik bei Schölvn der 13. Jahrgangsstufe, Universität Bremen 1987 (polykop.)
- Boehme, G.: Die Verwissenschaftlichung der Erfahrung wissenschaftsdidaktische Konsequenzen; in: Duit, R. et al. (Eds.): *Alltagsvorstellungen und naturwissenschaftlicher Unterricht*; Köln 1981, p.85-113
- Bormann, M.: Das Schölvorverständnis zum Themenbereich "Modellvorstellungen zu Licht und Elektronen" in Kuhn, W. (Ed.): *Didaktik der Physik, Vorträge, Physikertagung 1987 Berlin, Gießen 1987*
- Brown, H.J.: *Perception, Theory and Commitment - The New Philosophy of Science*, Chicago: Precedent 1977
- Champagne, A./Klopfer, L./Anderson, I.: Factors influencing Learning of Classical Mechanics; in: *Am.J.Phys.* 48 (1980), p.1074-1079
- Clement, J.: Student Preconceptions in Introductory Mechanics; in: *Am.J.Phys.* 50 (1982), p.66-71
- Driver, R.: Pupils' Frameworks in Science; in: *Eur. J.Sci.Educ.* 3 (1981), p.93-101
- Duit, R./Jung, W./v. Rhoebeck, Chr.: Aspects of Understanding Electricity: Proc. of an International Workshop at the Paed. Hochschule Ludwigsburg, Sept.10-14, 1984; *IPN-Arbeitsberichte*, Kiel, 1985
- Einstein, A.: Über einen die Erzeugung und Verwandlung des Lichts betreffenden heuristischen Gesichtspunkt; in: *Annalen der Physik*, 17, 1905, p.132
- Frey, K.: Research in Science Education in the Federal Republic of Germany: the state of the art in 1984: Revised paper presented at the invited Symposium of the National Association for Research in Science Teaching (NARST) at New Orleans in April 1984
- Goeritz, G./Wiesner, H.: Wie verstehen Schölv Probleme der Quantenphysik 7 in: *Praxis der Naturwissenschaften - Physik* 1984, Heft 3, p.90
- Helm, H./Novak, J.D.: Proc. of the International Seminar: Misconceptions in Science and Mathematics: June 20-22, 1983, Cornell University, Ithaca, N.Y., USA
- Holz kamp, K.: *Wissenschaft als Handlung*, Berlin 1968
- Jung, W./Wiesner, H./Engelhardt, P.: Vorstellungen von Schölvn über Begriffe der Newton'schen Mechanik; Bad Salzdetfurth 1981
- Jung, W./Wiesner, H.: Verständnisschwierigkeiten beim physikalischen Kraftbegriff; in: *Physik und Didaktik* (1981), p.111-122
- Kelly, G.A.: *The Psychology of Personal Constructs*, New York: Norton 1955
- Kröger, M.H./Schecker, H.: Das Bild von der Wissenschaft Physik - Ergebnisse empirischer Untersuchungen zu wissenschaftstheoretischen Fragestellungen bei Schölvn und Lehrern der Sekundarstufe II, in: *Der Physikunterricht* 16 (1982), p.78-82
- Kuhn, Th.S.: *Die Struktur wissenschaftlicher Revolutionen*; Frankfurt/M. 1976
- Lakatos, I.: Falsifikation und die Methodologie wissenschaftlicher Forschungsprogramme; in: Lakatos, I./Mungrave, A. (Eds.): *Kritik und Erkenntnisfortschritt*, Braunschweig 1974
- Lenard, P.: Über die lichtelektrische Wirkung; in: *Annalen der Physik* 8 (1902), p.149
- McCloskey, M.: Irrwege der Intuition in der Physik; in: *Spektrum der Wissenschaft*, Juni 1983, p.88-99
- Niedderer, H.: Sachstruktur und Schölvfähigkeiten beim einfachen elektrischen Stromkreis; Dissertation Kiel 1972

- Niedderer 1975 Niedderer, H.: Didaktische Sachstruktur-Analyse - Theoretischer Ansatz und Beispiele aus der Elektronik; in: Dahncke (Ed.): Zur Didaktik der Physik und Chemie, Hannover 1975
- Niedderer 1982a Niedderer, H.: Probleme der Lebenswelt, Vorverständnis der Schüler, Wissenschaftstheorie der Physik als Determinanten für den Physikunterricht; in Fischler, H. (Ed.): Lehren und Lernen im Physikunterricht; Köln 1982, p.105-132
- Niedderer 1982b Niedderer, H. (Ed.): Wissenschaftstheorie und Physikunterricht; in: Der Physikunterricht 16, Heft 2, 1982
- Niedderer 1987 Niedderer, H.: A Teaching Strategy Based on Students' Alternative Frameworks - Theoretical Concept and Examples, Second International Seminar, Cornell University, 1987
- Osborne 1983a Osborne, R.J./Bell, B.F./Gilbert, J.K.: Science Teaching and Children's View of the World; in: Eur.J.Sci.Educ. 5 (1983), p.1-14
- Osborne 1983b Osborne, R.J., Wittrock, M.C.: Learning Science: A Generative Process, in: Science Education 67 (4) (1983), p.489-508
- Pfund 1987 Pfund, H., Duit, R.: Bibliography, Students' alternative frameworks and science education, Kiel, IPN, 1987 (2nd ed.)
- Redeker 1978 Redeker, B.: Untersuchungen zur Begriffsbildung im naturwissenschaftlichen Unterricht, Dissertation, Bielefeld 1978
- Redeker 1981 Redeker, B.: Zur Bedeutung des Vorverständnisses für das Lernen von Physik; in: physica didactica B (1981), p.107
- Schecker 1985 Schecker, H.: Das Schülervorverständnis zur Mechanik - Eine Untersuchung in der Sekundarstufe II unter Einbeziehung historischer und wissenschaftstheoretischer Aspekte, Dissertation Bremen 1985
- Schenk 1983 Schenk, B.: Entwicklung von Schülertheorien zur Mechanik in der Sekundarstufe II; ausgearbeitetes Manuskript eines Vortrages auf der Jahrestagung der GDGP 1983 in Siegen
- Strike 1982 Strike, K.A., Posner, G.J.: Conceptual Change and Science Teaching, Eur.J.Sci.Educ. 4 (1982), p.231-240
- Trowbridge 1981 Trowbridge, D.E./McDermott, L.C.: Investigation of Student Understanding of the Concept of Acceleration; in: Am.J.Phys. 49 (1981), p.242-253
- Viennot 1979 Viennot, L.: Spontaneous Reasoning in Elementary Dynamics; in: Eur.J.Sci.Educ. 1 (1979), p.205-221
- Warren 1979 Warren, J.W.: Understanding Force; London 1970
- Watts 1983 Watts, D.M.: A Study of Schoolchildren's Alternative Frameworks of the Concept of Force; in: Eur.J.Sci.Educ. 5 (1983), p.217-230
- Whitaker 1983 Whitaker, R.J.: Aristotle is not Dead; Student Understanding of Trajectory Motion; in: Am.J.Phys. 51 (1983), p.352-357
- Wolze 1986 Wolze, W.: Zur Entwicklung naturwissenschaftlicher Erkenntnisssysteme im Lernprozeß; IPN, Universität Kiel. 1986 (polykop.)

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Introduction

Constructivism is becoming one of the common words tossed about by psychologists, philosophers and educators. Depending on the user's orientation, the word has some kind of reference to the idea that both individuals and groups of individuals construct ideas about how the world works. It is also recognized that individuals vary widely in how they make sense out of the world and that both individual and collective views about the world undergo change over time. Constructivism is seen in contrast to positivism, logical positivism or empiricism that holds "true" knowledge is universal and stands in a kind of one-on-one correspondence with the way the world really works. The goal of knowing is to discover this true knowledge. This paper will examine approaches developed over the years by our research group (and other colleagues) to study and describe a view of learning and knowing that I will call human constructivism. I shall argue that it is important to link a viable theory of human cognitive learning with contemporary ideas in epistemology. I begin with consideration of how humans learn.

Human Learning

For almost three quarters of a century the dominant view of learning was that a stimulus (S) from the environment produced a response (R) from the organism and with repetition an S-R bond was formed such that given S was almost inevitably associated with a given R. Although this associationist or behaviorist theory of learning, based largely on animal experimentation in laboratories, never gained popularity in much of the world, in North America associationist views were not only popular but most

alternative "theories" of learning were eschewed or ridiculed. The rigid prescriptive nature of associationist psychology was consistent with and supported by the widely held positivist or empiricist views of the nature of knowledge and knowing made popular by Francis Bacon in 1620 and later by Karl Pearson (1900) and a hoard of philosophers of the "Vienna School". The leading philosophers/epistemologists of the early twentieth century worked to establish the hegemony of positivism by the 1930's and 40's. B.F. Skinner's Behavior of Organism published in 1938 was the epitome of wedding associationist psychology with positivist epistemology in an alliance that virtually swamped out other psychologies of learning in North America. The hegemony of associationist ideas dominated psychology and education until the 1970's. The failure of these ideas to describe and predict how scholars produce knowledge and how humans learn allowed new views of knowledge as "paradigm" construction (Kuhn, 1962) and evolving populations of concepts (Toulmin, 1972) to emerge. In psychology, cognitive views began to take hold and concern with meanings of knowledge as held by individuals began to dominate.

My own studies of learning began in 1955 with an effort to understand parameters of problem solving ability in the context of a college botany course (Novak, 1957). Rejecting the dominant associationist theories of the 1950's, I tried to design my research and a test of problem solving ability (Novak, 1961) on the basis of a cybernetic model (Wiener, 1948, 1954) of learning and an evolving "conceptual schemes" view of epistemology expressed in Conant's (1947) On Understanding Science. This model of learning considered the mind as an information processing unit wherein knowledge storage and information (knowledge) processing were separate components, with the latter being relatively stable over time and the knowledge store varying over time with new information and "feedback" information. The difficulty with the cybernetic model for me was that my Ph.D. thesis data and subsequent research data all pointed in a direction that

suggested information processing capacity and acquisition rate for new information was highly dependent upon the prior relevant knowledge store and the context of the problem solving or learning task (See Novak, 1977a, Chapter 8). When Ausubel's Psychology of Meaningful Verbal Learning was published in 1963, we saw immediately a better match between our research results and his assimilation theory of human learning. It took another decade, however, for our research group to become comfortable with Ausubel's theory and subsequently to modify and extend the theory in our work (Ausubel, Novak and Hanesian, 1978). During this decade we also moved from predominantly paper and pencil testing to adaptation of Piaget's clinical interview techniques (Pines, et al, 1978).

The principal contribution of Ausubel's theory was its emphasis on the power of meaningful learning, as contrasted with rote learning, and the explicitness with which he described the role that prior knowledge plays in the acquisition of new knowledge. In the epigraph to both his 1968 and 1978 editions of Educational Psychology: A Cognitive View, Ausubel stated:

If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.

Ausubel was not the first to emphasize the importance of prior knowledge in new learning. Bartlett's (1932) theory of memory held that "schemes" influence perception and recall of information, in a way similar to that where schemes are seen to operate in contemporary "cognitive science" views of learning and retention (see for example Estes, 1978). In contrast, assimilation theory places central emphasis on cognitive processes involved in acquisition of knowledge and the role that explicit concept² and propositional frameworks

²We define concept as a perceived regularity in events or objects designated by a label. Most concept labels are words and most of the 460,000 words in the English language are concept labels, many used to represent several different "regularities". Propositions are two or more concepts linked to form a meaningful statement, e.g., "sky is blue." For a good discussion of how children acquire early concepts and

play in acquisition. Kelley's (1955) "personal construct psychology" also gave emphasis to the role of prior learning in new learning, but not with an emphasis on specific concept and propositional frameworks. Kelley saw prior learning resulting in a "reperatory grid" of generic traits or "personal constructs" that influence how a person will think or respond to a new experience. It was also Ausubel's emphasis on school learning that has made his theory useful to us. In his Psychology of Meaningful Verbal Learning, Ausubel first developed his assimilation theory of cognitive learning showing how school learning could be made meaningful and that didactic instruction or reception learning need not be rote. The then popular idea that discovery learning, where the learner recognizes independently the regularities or concepts to be learned as a viable alternative, was rejected and he showed instead that didactic (reception) teaching could lead to meaningful learning. His idea of an "advance organizer" that could serve as a kind of cognitive bridge between new knowledge to be learned and existing relevant concepts and propositions in the learner's cognitive structure was one of Ausubel's most researched ideas, with most studies showing that advance organizers did not facilitate learning if principles of meaningful learning were not applied or evaluation failed to test for meaningful learning. (Ausubel, 1980.) The Piagetian idea of age-related general "stages" of cognitive development which limit new learning has been rejected by our group in favor of the idea that the quantity and quality of relevant concept and propositional frameworks are the primary limiting factor in new learning or problem solving, and these are age-related primarily in an experiential rather than developmental manner after about age four (Novak, 1977b; 1982).

A continuing problem for teachers and researchers who hold that prior knowledge is an important variable in new learning has been how to "assess what the learner already knows." Various paper and pencil tests have been tried, but proposition meanings (and word labels), see Macnamara, 1982.

the general consensus is that these are comparatively crude measures of prior learning, accounting perhaps for only ten percent of variance in total functional knowledge held by an individual. Clinical interviews have emerged as much more trusted indicators of the quality and quantity of relevant knowledge a learner possesses, but interview transcripts are notoriously laborious and difficult to interpret. Moreover, interviewing is not an evaluation tool teachers can use in routine class evaluation.

A significant breakthrough occurred in our work when we devised and refined the technique of "concept mapping" as a tool to represent conceptual/propositional frameworks, either as derived from clinical interviews or as constructed by the learners in our studies. Concept mapping subsequently proved to be a useful tool in planning instruction and helping students "learn how to learn" (Cardemone, 1975; Bogden, 1977; Stewart, et al, 1979; Gurley, 1982; Novak, Gowin and Johansen, 1983; Novak and Gowin, 1984; Hoz, 1987; Hoz, Kozminsky and Bowman, 1987; Alvarez and Risko, 1987; Pankriatius and Keith, 1987). A concept map used to plan this paper is shown in Figure 1. Two examples of concept maps drawn from interviews with Phil are shown in Figure 2, representing this student's understanding of the particulate nature of matter in grade 2 and 10 year's later in grade 12.

(Fig 1 & 2 about here)

Concept maps serve as a useful tool to illustrate key ideas in assimilation theory. Acquisition of new knowledge may range over a continuum from rote learning to highly meaningful learning (see Figure 3). Most school learning is relatively verbatim, arbitrary and nonsubstantive, and this is illustrated in Figure 2. Our subject (Phil) learned about molecules in grades one and two (through specially designed audio-tutorial lessons) and later learned about atoms, but his concept of molecule and atom were never adequately assimilated. As a result, in grade 12, Phil believed that molecules are made of atoms but erroneously believed that gases are made only of atoms. We also see persistence of the

idea (misconception) that smell molecules or sugar molecules dissolve into water molecules and hence move with the water molecules. In extreme cases of rote learning we observe that students may be able to give a correct, verbatim definition of a concept but cannot relate it substantively to other concepts in their concept map. This is seen frequently in class instruction when concept maps are used as an evaluation tool, especially after a short unit of study. Most information learned by rote is forgotten in three to six weeks, unless it is much rehearsed and "overlearned" in which case it may be recalled years later but is not relatable to other relevant knowledge the person holds.

(Figure 3 about here)

Two key additional ideas in assimilation theory are progressive differentiation and integrative reconciliation. As new concepts are linked non-arbitrarily to an individuals cognitive structure (represented, for example, in a concept map), progressive differentiation occurs. In our example, assimilation of the concept of atom led to some differentiation of Phil's cognitive structure. Recognition that different atoms make up different elements also showed cognitive differentiation. Integrative reconciliation occurs when sets of concepts are seen in new relationships. Phil did "change his mind" about the composition of matter but failed to integratively reconcile how gases (or anything else) can be made of molecules and their component atoms. He also failed to reconcile the concept that molecules may move independently in a fluid and smell or sugar molecules are not absorbed into water molecules. Part of the learning difficulty of Phil was his failure to acquire a valid superordinate concept of the particulate nature of matter and to integrate atoms and molecules into this concept. Superordinate learning occurs only rarely, since subsumption is usually possible and sufficient, but when it occurs, significant integrative reconciliation of subordinate concept structures usually results, and also further concept differentiation.

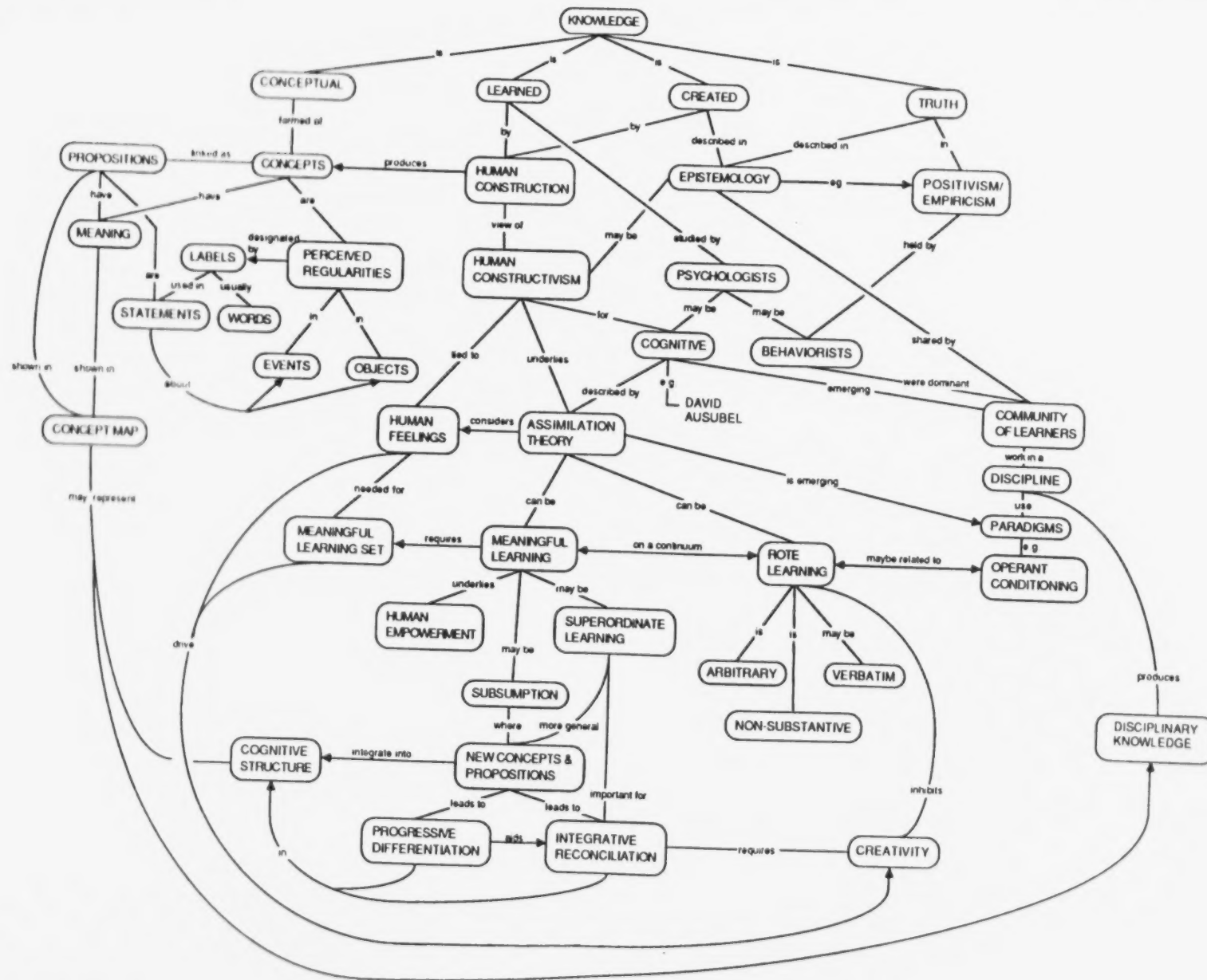


Figure 1: A concept map showing the key concepts and propositions presented in this paper.

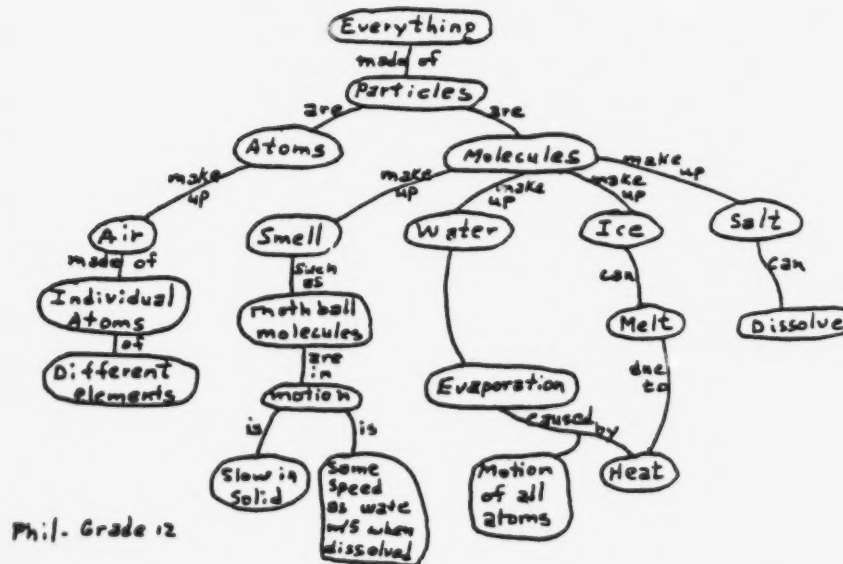
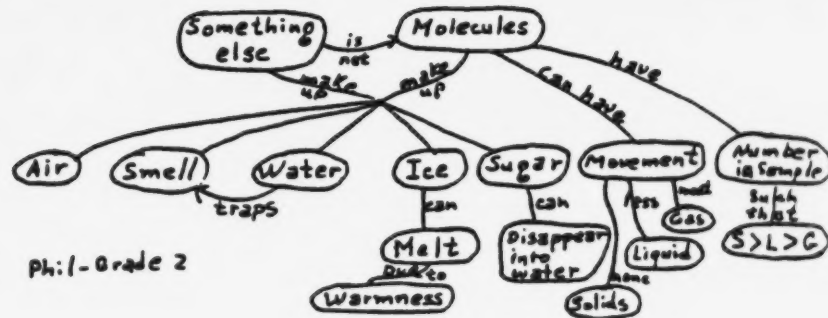


Figure 2:

Two concept maps drawn from interviews with a student (Phil) in grade 2 (top) and grade 12 (bottom). Note that even after junior high school science, biology, physics and chemistry, Phil has not integrated concepts of atoms and molecules with states of matter nor corrected his misconception that sugar or smell molecules are "in" water molecules.

Meaningful Learning

Creative production

Non-arbitrary, non-verbatim, substantive incorporation of new knowledge into cognitive structure.
Deliberate effort to link new knowledge with higher-order, more inclusive concepts in cognitive structure.
Learning related to experiences with events or objects.
Affective commitment to relate new knowledge to prior learning.

Most school learning

Rote Learning

Arbitrary, verbatim, non-substantive incorporation of new knowledge into cognitive structure.
No effort to integrate new knowledge with existing concepts in cognitive structure.
Learning not related to experience with events or objects.
No affective commitment to relate new knowledge to prior learning.

Figure 3: The rote/meaningful learning continuum as seen an assimilation theory. In our studies (and reports of others) we see that most school learning is near the rote end of the continuum.

Concept maps are a tool or heuristic to illustrate cognitive or meaning frameworks that individuals possess and by which they perceive and process experiences. If new experiences provide a basis for meaningful learning, new concepts will be added to an individual's concept map and/or new relationships will be evident between previous concepts. Over time concept relationships may take on new hierarchical organization, as observed, for example, by Cullen (1984) in a college chemistry course where the concept of entropy was either not known or held a subordinate position in students' cognitive structure. After instruction using a specially designed study guide emphasizing the entropy concept, it became a superordinate concept in those students who demonstrated the best understanding of chemistry principles. Similar results have been reported by Hoz (1987), Feldsine (1987), and others. Experts differ from novices in a field of study not only in that they have more concepts integrated into their cognitive frameworks but also in the kind of conceptual hierarchies they possess and the quality and extent of propositional linkages they possess between subordinate and superordinate concepts. (See for example, Chi, Feltovich and Glaser, 1981; Novak, in press). Concept maps are proving to be a useful tool to identify and help students "correct" misconceptions, as several papers in this and our earlier seminar illustrate (Helm & Novak, 1983).

There is a growing body of evidence on the neurobiology of brain function that suggests new learning involves not multiple neuron to neuron linkages and hundreds or even tens of thousands of neuronal linkages may be involved in the acquisition of a single new concept. Moreover, greater or lesser numbers of axons and dendrites of each neuron may be involved and varying degrees of synaptic transmitter or inhibitor channels may be formed at each synapse. The net effect is that new learning of a single concept, if it is substantively incorporated through meaningful learning, will involve many neurons in many regions of the brain, and constructive neuronal changes may continue for hours or days

after learning. During learning, neurons not only form new synapses with one another and new channels for secretion of transmitter chemicals, but also transmission inhibiting compounds may be secreted. This may account in part for "learning shock" and retroactive interference, two observed psychological phenomena where previously learned material is not recallable perhaps until a later point in time. This delayed facilitation effect, or short term inhibition, may be illustrated in a concept map. When a single concept is added to an individual's concept map through meaningful learning all linked concepts in that person's cognitive structure will be modified over time to some extent. Maps drawn at a later date often show some new or different linkages, and occasionally some significant new "cross-links" that may represent new integrative reconciliation of prior concepts. The "creative insights," reported in biographies of genius, occurring often days or weeks after intense study, are also evidence of gradually changing neural (and psychological) networks. All related concepts and propositions, at least in some small way, take on new meanings. The implications of current knowledge in neurobiology as it relates to concept mapping is discussed more extensively by MacGinn (1987).

We expect to see further evidence from studies of brain functioning to be even more supportive of concept maps as valid indicators of learning and also support for their effectiveness as a kind of metaphor to relate psychology of human learning with the neurobiology of human brain functioning. During my sabbatical studies at the University of West Florida next year, I plan to explore with Professor Dunn possible relationships between neural activity patterns observed using brain encephalographic scans (Dunn, 1987) and patterns of concept map construction prior to and following cognitive learning tasks. Nothing may come of this, but Dunn believes (personal communication) that relationship between encephalographic scans and concept map production may be found for selected subjects. If so, the results could be provocative at the least.

Knowledge Creation

That humans learn is self evident. It is also self evident that humans construct new knowledge, for the store of knowledge in any culture increases with time. What is not self evident are the processes by which humans construct new knowledge. As civilization emerged from the Dark Ages, knowledge about the universe and the workings of nature began to expand at an ever increasing rate. Oriental cultures continued to advance and were not constrained by the Dark Ages; however, it was in the Western cultures where the scientific experiment was invented and modern science began to blossom. It was natural that numerous philosophers/epistemologists should begin to write their descriptions of how humans increased this knowledge store. For Francis Bacon (1620), Karl Pearson (1900) and many other early epistemologists, the truth lay waiting in nature. Man's task was to "discover" these truths by careful observation and experimentation. Communities of scholars emerged who described various views on how nature's secrets were to be unearthed and "truth" revealed. Bacon (1620) wrote:

The subtly of nature is far beyond that of sense or of the understanding; so that specious meditations, speculations and theories of mankind are but a kind of insanity. (p 107)

And much later Pearson (1900) wrote:

The civil law is valid only for a special community at a special time; the scientific law is valid for all normal human beings, and is unchanging. (p 87)

The right of science to deal with the beyond sense-impressions is not the subject of contest, for science confessedly claims no such right. (p 110)

With the accelerating pace of "scientific discovery" in the twentieth century, many philosophers, scientists and mathematicians turned their substantial intellectual talents to the study of epistemology, especially the epistemology of science. The more popular varieties of epistemology gave careful attention to tests for truth and falsity and criteria to be applied. These scholars known variously as positivists, logical positivists or empiricists, placed

central emphasis on "proof and refutation." The reign of "positivist" epistemology was nearly absolute until the middle of the twentieth century. One of the problems of this epistemology is that it did not attract much interest from scientists and mathematicians--perhaps because it did not help them do what they were doing. It was probably not surprising that outstanding scholars/scientists such as James Conant should have been the first to espouse what Brown (1979) called "the new philosophy of science." And when Conant's protégé, Thomas Kuhn, published his Structure of Scientific Revolutions (1962) the walls of the positivist's bastion began to crumble. Even from within, the positivist protégé, Karl Popper, moved away from positivism and in his 1982 book he wrote:

Everybody knows nowadays that logical positivism is dead. But nobody seems to suspect that there may be a question to be asked here - the question 'Who is responsible?' or, rather the question 'Who had done it?'... I fear that I must admit responsibility. (p 88)

As Strike (1987) has noted, positivists were not fools and they knew that human understanding was built on more than a "logic of discovery." What they uniformly failed to describe was how humans construct concepts and how their conceptual frameworks become indeed their "perceptual goggles" to permit them to see what they see in their inquiries and to guide them in constructing new inquiries. Kuhn's (1972) description of the "paradigms" that guide the scientist and Toulmin's (1972) idea of "evolving populations of concepts" seemed to be much closer to the reality the working scientists face day to day. They do indeed construct new knowledge, but this is not truth, and much of the knowledge changes repeatedly in the lifetime of a scientist. Von Glasersfeld (1983) has argued that "radical constructivism" does not seek a description of the "truth," nor subscribed to the idea that in research we progress toward the truth. The issue now seems to center more on how to facilitate creative production, rather than how to tighten the criteria of proof or refutation.

Human Constructivism

My thesis is that we must examine closely the linkage between the psychology of human learning and philosophy knowledge. Creating new knowledge is, on the part of the creator, a form of meaningful learning. It involves at times recognition of new regularities in events or objects, inventing new concepts or extending old concepts, recognition of new relationships (propositions) between concepts and, in the most creative leaps, major restructuring of conceptual frameworks to see new higher order relationships. These processes can be viewed as part of the process of assimilative learning, involving addition (subsumption) of new concepts, progressive differentiation of existing concepts, superordinate learning (on occasion) and significant new integrative reconciliations between concept frameworks. The creative person is a member of a community of learners all of whom share many concept meanings but each of whom holds his/her own idiosyncratic conceptual hierarchy. The individual most able to add to or restructure his/her conceptual framework is, in time, recognized as the most creative in that community. And, over time, the population of concepts and concept relationships held by the community evolves, according to Toulmin (1972), or for the individual, progressively differentiates and reintegrates according to assimilation theory.

As far as we know, only humans use language symbol systems to code the regularities they perceive and hence construction of new meanings and construction of new knowledge using symbol systems is uniquely human. Human constructivism, as I have tried to describe it, is an effort to integrate the psychology of human learning and the epistemology of knowledge production. I place emphasis on the idea that in both psychology and epistemology we should focus on the process of meaning making that involves acquisition or modification of concepts and concept relationships.

Some of the conceptual frameworks we seek to develop in our students are those that deal with epistemology. To this end we have found the use of a heuristic developed by Gowin (1981) to be of value. Figure 4 shows an example of the Vee heuristic applied to a junior high school laboratory activity. The Vee shown has ten key "epistemic elements," those component of knowledge that when operating together permit us to construct or examine any unit of knowledge. All are necessary to understand the structure and/or creation of knowledge.

(Figure 4 about here)

The Vee represents an "event centered constructivist" view of knowledge (see Gowin, 1987). We center our attention on the construction of concepts, which we have defined as perceived regularities in events or objects designated by a label. Since all objects exist in time and space, it is reasonable to see the creation of knowledge as a search for regularities in events, or as is often the case, for regularities in records of events. No one has observed atoms disintegrating, but a cloud chamber or geiger counter permits us to make records of these events, and from these records we construct our knowledge claims. Often we transform our records, using photographs, computer processing, tables, graphs, etc., and each of these transformations is guided by one or more principles, including not only principles relating to the event we are studying but often, also, whole sets of principles that relate to the record making or record transforming tools that we employ. It is oversight or limitations of the latter that commonly leads to misinterpretation or misunderstanding of events or records. Even in the best case, the meaning of our records is always interpreted using our existing concepts, principles, theory and philosophy and since these are limited and evolving, we can only make claims (not truth statements) about how we believe the piece of world we are studying works.

The Vee heuristic also serves to emphasize the human and value-based character of knowledge and knowledge production.

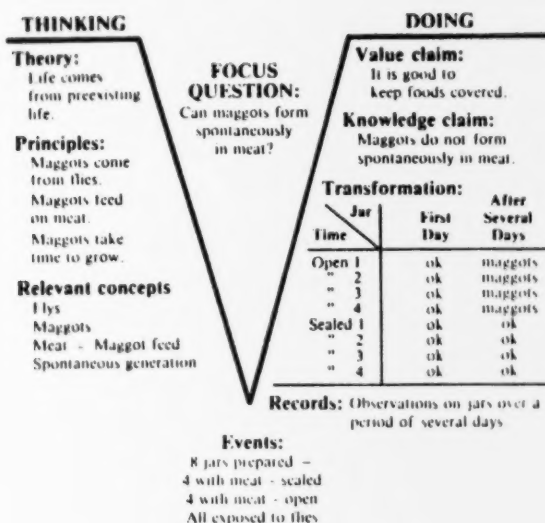


Figure 4: An example of a Vee diagram prepared in a class discussion with seventh grade biology students. The Vee heuristic can help students to understand the constructed nature of knowledge and to take charge of their own meaning making in science or math activities.

Whether we choose to be a historian, chemist or poet depends upon our philosophy and commitments. The events we choose to observe, the questions we ask and the records and record transformations we choose to make all involve value decisions: what do we care about and what price are we willing to pay in time or dollars and personal sacrifice? And if we stop to reflect, it is easy to see that every knowledge claim we construct can lead us to one or more value claims, claims about the worth of our knowledge or its application. The objective, value-free character of science or other fields of knowledge creation was only a positivist's myth sustained by ignoring the myriads of subjective and value-based decisions that everyone involved in knowledge production must make. It is this constructive integration of thinking, feeling and acting that gives a distinctively human character to knowledge production. With geniuses, we usually judge this synthesis good and praise it highly, although it may take generations for this recognition to occur. It is often human vanity that denies the creative artist, poet or scientist the recognition they deserve.

A New Synthesis

To me there is a new excitement about psychology, epistemology and education: there is the excitement of a new synthesis. Emerging consensus (see Linn, 1987) in psychology points toward the crucial role that concepts and concept relationships play in meaning making by humans, and the important role that language plays in coding, shaping and acquiring meanings. In philosophy there is also an emerging consensus in epistemology that characterizes knowledge and knowledge production as evolving frameworks of concepts and propositions. The almost infinite permutations of concept-concept relationships allow for the enormous idiosyncrasy we see in individual concept structures, and yet there is sufficient commonality and isomorphism in meanings so that discourse is possible and sharing, enlarging and changing

meanings can be achieved. It is this reality that makes possible the educational enterprise.

What remains to be demonstrated is the positive results that will occur in schools or other educational settings when the best that we know about human constructivism is applied widely. To my knowledge, no school comes close to wide scale use of such practices, even though there are no financial or human constraints that preclude this. What we observe in our studies of learning in school or university settings is an almost ubiquitous pernicious, pervasive, positivism. This right/wrong true/false instructional and evaluation pattern justifies and rewards rote-mode learning and often penalizes meaningful learning. The importance of constructivist views for the redesign of science and mathematics instruction and for teacher education has been put forth by others (Cobb, in press, a; b); Confrey, 1985; Driver and Oldham, 1985; Pope, 1985).

The only thing we need to do is to "change our minds" about how teaching and learning can proceed using what we know. The challenge of this Seminar is: How do we get people to change their minds, (about teaching and learning) and to alter their conceptual frameworks or what I called in 1983, their LIPHS - their limited or inappropriate propositional hierarchies?

REFERENCES

- Alvarez, Marino C. and Victoria J. Risko. (1987) "Concept Maps and Vee Diagrams: A Visual Representation of Children's Thinking." Paper presented at AERA meetings, Washington, D.C.
- Ausubel, David P. (1963) The Psychology of Meaningful Verbal Learning. New York: Grune and Stratton.
- Ausubel, David P. (1968) Educational Psychology: A Cognitive View. New York: Holt, Rinehart and Winston.
- Ausubel, David P., Joseph D. Novak, and Helen Hanesian. (1978) Educational Psychology: A Cognitive View, (second edition). New York: Holt, Rinehart, and Winston.
- Bacon, Sir Francis. (1952) Advancement of Learning, Novum Organum, and New Atlantis. Chicago, London, Toronto: William Benton, Publisher; Encyclopedia Britannica, Inc.
- Bartlett, F.C. (1932) Remembering. Cambridge: Cambridge University Press.
- Bogden, Christopher A. (1977) "The Use of Concept Mapping as a Possible Strategy for Instructional Design and Evaluation in College Genetics." M.S. Thesis, Cornell University, Department of Education.
- Cardemone, Peter F. (1975) "Concept Mapping: A Technique of Analyzing a Discipline and its Use in the Curriculum and Instruction in a Portion of a College level Mathematics Skill Course." M.S. Thesis, Cornell University, Department of Education.
- Chi, Michelene, Paul J. Falovich and Robert Glaser. (1981) "Categorization and Representation of Physics Problems by Experts and Novices." Cognitive Science 5(2): 121-152.
- Cobb, Paul. (In press, a) The Tension Between Theories of Learning and Instruction In Mathematics Education. Educational Psychologist.
- Cobb, Paul. (In press, b) "Information Processing Psychology and Mathematics Education -- A Constructivist Perspective." Journal of Mathematical Behavior.
- Confrey, Jere. (1985) "A Constructivists View of Mathematics Instruction." Paper presented at the Annual Meetings of the American Education Research Association, Chicago, IL.

- Conant, James B. (1947) On Understanding Science. New Haven: Yale University Press.
- Cullen, John Francis, Jr. (1983) "Concept Learning and Problem Solving: The Use of the Entropy Concept in College Teaching." Ph.D. Thesis, Cornell University, Department of Education.
- Driver, Rosalind and Valerie Oldham. (1985) "A Constructivist Approach to Curriculum Development in Science." Paper presented at BERA meeting, Sheffield England.
- Dunn, Bruce R. (1987) "Tentative Outline For a Psychophysiological Model of Cognitive Processing." Unpublished paper, University of West Florida, Pensacola, Florida.
- Estes, William K. (1978) Handbook of Learning and Cognitive Processes. Volume 5: Human Information Processing. New York: John Wiley and Sons.
- Feldsine, John. (1987) The Construction of Concept Maps Facilitates the Learning of General College Chemistry: A Case Study. Unpublished Ph.D. thesis, Cornell University, Ithaca, NY. (See also his paper in these Proceedings.)
- Gowin, D. Bob. (1981) Educating. Ithaca, NY: Cornell University Press.
- Gowin, D. Bob. (1987) "Changing the Meaning of Experience: Empowering Teachers and Students Through Vee Diagrams and Principles of Educating to Reduce Misconceptions in Science and Math." Paper presented at the 1987 Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, July 26-29, 1987, Department of Education, Cornell University, Ithaca, NY.
- Gurley, 'Laine I. (1982) "Use of Gowin's Vee and Concept Mapping Strategies to Teach Responsibility for Learning in High School Biological Sciences." Ph.D. Thesis, Ithaca, NY: Cornell University.
- Helm, H. and J. Novak. (1983) Proceedings of the International Seminar Misconceptions in Science and Mathematics. Ithaca, NY: Cornell University, Department of Education.
- Hoz, Ron. (1987) "Dimensions of Teachers' Knowledge Structure and Their Identification by Concept Mapping." Paper presented at AERA Meetings, Washington, D.C.
- Hoz, Ron, Ely Kozminsky and Dan Bowman. (1987) "Evaluating Learning Through Concept Mapping: A Study of Student's Cognitive Structure in Earth Science Course." Unpublished paper, Ben Gurion University, Beer-Sheva, Israel.
- Kelly, George A. (1955) The Psychology of Personal Constructs. New York: Norton and Company.
- Kuhn, Thomas S. (1962) "The Structure of Scientific Revolutions," International Encyclopedia of Unified Science, (second edition). Enlarge Vols. 1 and 2: Foundations of the Unity of Science, Vol. 2, No. 2. Chicago: University of Chicago Press.
- Linn, (1987) "Establishing a Research Base for Science Education: Challenges, Trends and Recommendations." Journal of Research in Science Teaching 24(3):191-216.
- MacGinn, Nina. (1987) "Neurophysiological Rationale for Concept Mapping." M.S. Thesis, Department of Education, Cornell University.
- MacNamara, John. (1982) Names for Things: A Study of Human Learning. Cambridge, MA: MIT Press.
- Novak, Joseph D. (In press) "Learning of Science and the Science of Learning." Studies in Science Education.
- Novak, Joseph D. (1985) "Learning Science and the Science of Learning." Paper presented at International Seminar on the Scientists Thinking Tools, University of East Anglia.
- Novak, Joseph D. (1982) "Psychological and Epistemological Alternatives." In Jean Piaget: Consensus and Controversy, Sohan Modgil and Celia Modgil, editors, pp. 331-349. London: Holt, Rinehart and Winston.
- Novak, Joseph D. (1977b) "An Alternative to Piagetian Psychology for Science and Mathematics Education." Science Education 61(4): 453-477.
- Novak, Joseph D. (1977a) A Theory of Education. Ithaca, NY: Cornell University Press.
- Novak, Joseph D. (1961) "An Approach to the Interpretation and Measurement of Problem Solving Ability." Science Education, 45(2): 122-131.
- Novak, Joseph D. (1957) "A Comparison of Two Methods of Teaching a College General Botany Course." Ph.D. Thesis, University of Minnesota.

- Novak, J.D., D. Bob Gowin and Gerard T. Johansen. "The Use of Concept Mapping and Knowledge Vee Mapping with Junior High School Science Students." Science Education, 67(5).
- Pankratius, William J. and Thomas M. Keith. (1987) "Building an Organized Knowledge Base: Concept Mapping in Secondary School Science." Paper presented at the 1987 Meetings of the National Science Teachers Association, Washington, D.C., March 28, 1987.
- Pearson, Karl. (1900) The Grammar of Science (second edition). London: Adam and Charles Black.
- Pines, A.L., J.D. Novak, G.J. Posner, and J. VanKirk. (1978) The Clinical Interview: A Method for Evaluating Cognitive Structure. Research Report #6, Department of Education, Cornell University.
- Pope, Maureen. (1985) "Constructivist Goggles: Implications for Process in Teaching and Learning." Paper presented at BERA meetings, Sheffield, England.
- Skinner, B.F. (1938) The Behavior of Organisms: An Experimental Analysis. New York, London: D. Appleton-Century Co., Inc.
- Stewart, James, Judith VanKirk, and Richard Rowell. (1979) "Concept Maps: A Tool for Use in Biology Teaching." The American Biology Teacher, 41(3): 171-175.
- Strike, Kenneth A. (1987) "Toward A Coherent Constructivism." Paper presented at the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, NY.
- Toulmin, Stephen. (1972) Human Understanding, Volume 1: The Collective Use and Evolution of Concepts. Princeton, NJ: Princeton University Press.
- von Glasersfeld, Ernst. (1984) "An Introduction to Radical Constructivism." In P. Watzlawick (ed.) The Invented Reality (17-40). New York: Norton.
- Wiener, Norbert. (1954) The Human Use of Human Beings, (second edition). Garden City, NY: Doubleday and Company.
- Wiener, Norbert. (1948) Cybernetics. New York: John Wiley and Sons.

The Physico-chemical Reduction of Life:
Paradigm, Biologists and Human Values

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Schwab's ideas (1964) about the structure of knowledge and education, though written early in the sixties, have lost nothing of their philosophical value or of their actuality. We found it helpful to develop our arguments as stemming from his notions and framework. We shall, therefore, open by presenting those essential ideas of Schwab that are relevant to the present discussion.

In developing the notion that every body of knowledge has its own structure, Schwab coined his idiosyncratic term--"the substance structure." By this term he referred not only to the set of major concepts and principles, forming together a specific conceptual structure, but also to the most basic philosophical assumptions which have yielded those concepts and principles. Kuhn's notion of "a paradigm" (1970) is quite close to Schwab's notion of "a substance structure." Since

many readers might be quite familiar with Kuhn's ideas we shall use both terms (a substantive structure and a paradigm) interchangeably, in this paper.

A Structure of Knowledge--a Paradigm

Educators, in general, have been relatively much more aware of the importance of emphasizing major concepts and principles, in teaching a subject matter, than of the importance of spelling out the underlying philosophical assumptions. For Schwab, helping students understand the nature and role of the substantive structure in a specific science of nature is also of the main elements of teaching the "nature of science."

The role of "a substantive structure" (a paradigm), in any discipline, is always in initiating and guiding research. Without the pre-existence of some conceptual structure no genuine research can be conceived. It is only within certain conceptual framework that a phenomenon may be perceived as presenting a problem. The hypotheses proposed to solve the problem and the guiding questions of the research, all draw their concepts and terms from the original conceptual framework. Consequently, the kinds of desired data and of "appropriate experiments" are already

determined (through the guiding questions) by the same framework. Findings (data) are meaningless unless they are explained (by way of selecting, organizing and transforming them) by some conceptual framework, which normally is again the original structure. The interpreted findings are added now to the structure which originated them, contributing to its further development and differentiation. (See Figure 1)

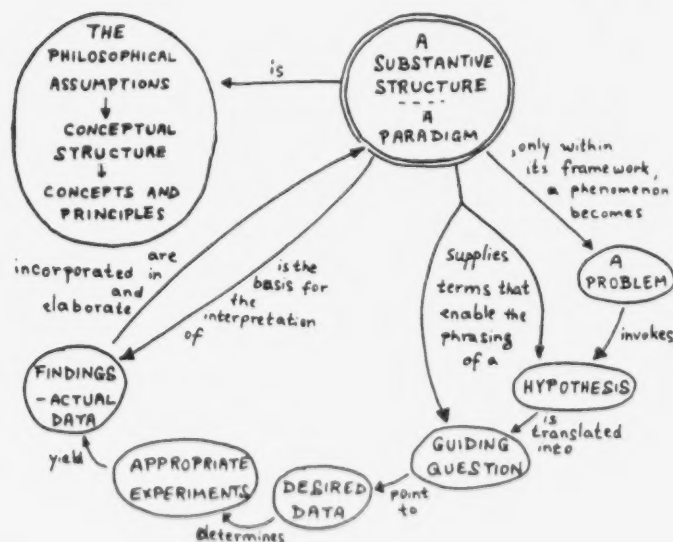


Figure 1. Paradigm: The framework of research.

We may arrive at a completely different kind of research when a different paradigm is adopted or constructed. (We avoid in this paper the issue of what are the processes and mechanisms of

"paradigm shifts" or of "conceptual changes.")

Consider for example two cases; a case in which one works within the paradigm of Skinner's behaviorism and alternatively a case in which one works within Piaget's paradigm of cognitive assimilation and accommodation. In the two cases, different problems would be identified, different kinds of experiments performed, yielding different kinds of data, explained by different criteria and notions.

The choice between two rival conceptual structure and even between two global paradigms relies on the researcher's weighing together the "validity" of each. By "validity" it is meant here the extent to which each paradigm succeeds to provide a convincing representation of the richness and complexity of the reality. In so doing, the researcher certainly applies his own previous philosophical biases.

Educational Implications of Identifying the Substantive Structure of a Knowledge

Schwab (1964) points out two important educational implications brought up by the identification and analysis of the substantive structure of some body of knowledge. In drawing the first implication Schwab makes the point that recognizing the characteristics of the substan-

tive structure of a specific subject matter helps the educator to anticipate the cognitive difficulties that the student might encounter. He suggests that one of the basic cognitive difficulties, that a student faces, evolves from the gap between the conceptual structure of the disciplines (stemming from a specific set of philosophical assumptions) and the cognitive structure of the student (stemming from a different set of assumptions, also of philosophical nature). This gap is the source of the phenomenon, recently named "students' alternative frameworks" (Driver and Easley, 1978). This phenomena leads to the appearance amongst students of various "mis-conceptions," the focus of the present seminar.

The second implication drawn by Schwab is that by identifying the substantive structure of a subject matter, with its full depth, we might know better how to draw our students' attention to the nature of research and to the nature of the knowledge, generated by that research.

After identification and analysis of a substantive structure of a discipline, we should be better prepared to demonstrate to our students the tentative nature of knowledge and its dependence upon the original paradigm. This

should help students to realize that knowledge is always being constructed within certain framework rather than being discovered directly from reality.

Thus, we have two implications; one of a cognitive nature and the other of a philosophical-epistemological nature. Since about ten years ago, science educators have recognized that there is a close interconnection between the two (Novak, 1977; Driver and Easley, 1978; Nussbaum 1983, 1985). It is worth noticing that Schwab recognized these two implications in early stages of the major curricula development of the sixties. However, apparently, at that time the educational atmosphere was not ripe yet for the appreciation of their importance and their interconnection, for teaching and research purposes.

Concurrent and Successive Paradigms

Schwab emphasizes that the disciplines of the humanities and the social studies differ from those of the natural sciences in many respects. One respect is that in the first ones one finds concurrent rival paradigms while in the last ones it seems that in each of natural sciences there is only a single ruling paradigm, which was arrived at through a linear successive process of paradigm changes. (See Figure 2)

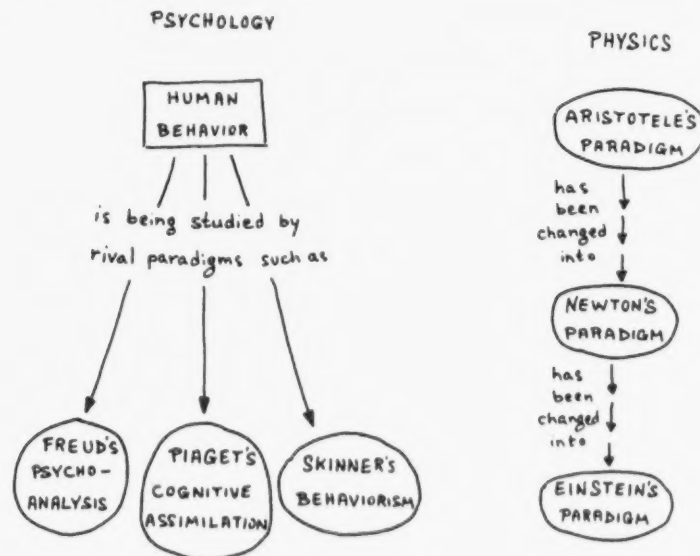


Figure 2. Concurrent paradigms in psychology and successive paradigms in physics.

Physics may be a good example of this process. In teaching the humanities and social studies it seems relatively easy to present students with the idea of what a paradigm is, through showing the role of rival paradigms as they parallelly function in current research. However, Schwab asserts, in the natural sciences conveying the notion that all our scientific knowledge is tentative, since it relies on a paradigm which is likely to undergo changes (as the history of science has shown), is indeed an uneasy educational task. This is so because students are likely to be locked within

the present ruling paradigm and therefore not being aware of its role. Schwab's suggestion was that in science education we must turn to historical case studies of paradigm change, for this educational purpose.

Biology, like physics, seems also to present a linear process of successive changes of paradigms in which various vitalistic approaches were finally replaced by the mechanistic paradigm. The vitalistic paradigm presumed that living things demonstrated intentions and free will (teleology) resulting from the existence within them of some nonmaterial-"vital" entity. The mechanistic paradigm (originated by Claud Bernard and others, in the 19th century) rejected all teleological explanations of organismic behavior, substituting it with simple mechanistic explanations. The modern mechanistic paradigm of biology assumes that all life processes are completely governed by principles of "molecular randomness" and "physical causality" ("chance and necessity") and of "cybernetic control." It is clear that the two notions of "physical causality" and "randomness" are the antitheses to the basic notions of the "vitalistic" approach, namely "intentions" and "free will." (See Figure 3) The famous historical dispute between Lamarkism and Darwinism is only

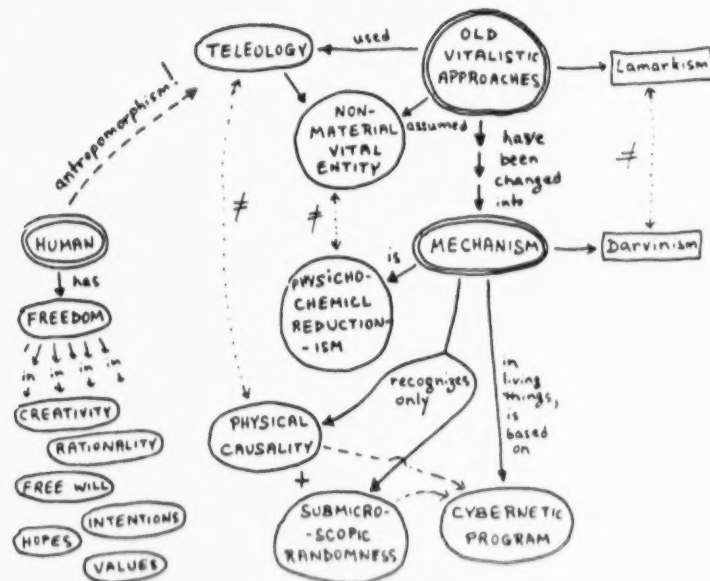


Figure 3. The mechanism-reductionism of biology and the incompatible humanistic view of man.

one specific application of the more basic dispute between the two paradigms. Since modern "mechanism" assumes the reducibility of all life phenomena to physico-chemical processes it is also known as "reductionism."

Biology and the Humanities

As biology teachers, we know that the aforementioned historical dispute is still alive and may reappear amongst students in the classroom. Research (Brumby 1979; Kargbo, et al. 1980) has shown that many students who had studied

the Darwinian theory of evolution still maintained teleological notions, which are the essentials of Lamarckism. We usually refer to such examples as misconceptions. The source for this specific misconception is usually identified as the psychological act of "antropomorphism." It is assumed that the mistaken students have performed an "illegitimate" rationale transfer from the domain of human life to the domain of biology. But, is it only the rationale transfer which is logically or philosophically "illegitimate"? Is it not the case that biological sciences relates to the human phenomenon as being the content of one specific chapter in the study of mammals?

Indeed, many biologists hold today that the very traditional view of man, namely that man is being part of the physical nature (the body) and at the same time is separate from it (the mind), is a misconception that requires correction (Churchland, 1986). They deny the idea that man has nonmaterial-mental qualities, such as "free will" and "intentions", and argue that these apparent qualities are completely reducible to physico-chemical processes. Some of these biologists follow on and explicitly propose that all "liberal arts" should be subsumed, after radical revisions of concepts and terms, under the physico-chemical paradigm.

Most of the people who are deeply involved with the humanities (the liberal arts) and almost all laymen would probably strongly reject the proposal that human freedom is only an illusion to be corrected by physico-chemical reductionism.

Are we, educators, willing to claim that traditional humanism is a misconception? Indeed, most biology teachers and textbooks do not go all the way to make explicitly this claim. However, this claim is made implicitly by regular biology education. The fact that we do not witness, in school education, a "clash" between the humanities and biology is not because no real dilemma exists, but because both types of disciplines seem to be superficially taught. Is such a "clash" unavoidable? Is it necessary for one to commit himself to one of two paradigms while rejecting completely the other? There might be two versions of biological reductionism each of them presenting a substantially different view. The two versions are:

- a) Reductionism is a very successful paradigm and therefore represents some absolute truth about the essence of living things, including man.
- b) Reductionism is a very successful paradigm playing an important but

limited epistemological role in studying biological phenomena.

Aside from these two versions of reductionism stands the humanist paradigm which presumes the existence of some nonmaterial entity (mind, psyche) which is responsible for much of his behavior.

The first version of reductionism and the traditional humanism cannot tolerate each other's view and they mutually exclude each other. The second version of reductionism is also not compatible with traditional humanism in their assumptions and methodologies. However, they can tolerate each other's view, since the second version agrees that current biological knowledge is not only tentative but is also conditional with relation to the ultimate validity of the reductionist philosophy. It is worth noticing in this respect that the second version is in line with the "constructivist" approach in the philosophy and history of science while the first version is in line with the "positivist" approach.

Teaching the Humanism vs. Biological Reductionism Dilemma

My following arguments, evolve from the conclusion of Schwab's (1964) discussion of the structure of knowledge, saying that the teaching

of science must include the treatment of the philosophical-epistemological aspects of each scientific discipline. The inclusion of a treatment of the dilemma of the humanities vs. biology in our curriculum is educationally important for the following reasons: (a) the treatment of the dilemma provides understanding of the epistemological nature of the biological research and knowledge. The dilemma provides example of concurrent paradigms which each of them is not capable of explaining everything. Each of these paradigms explains reality using different philosophical grounds and conceptual frameworks. Each paradigm has limits and Man must apply both as parallel intellectual paths to explain the complex reality. The very understanding that there are basic unsolvable problems is a tremendous educational gain. (b) Those among us who are unwilling to give up our traditional humanistic view of man must deal with this dilemma from the second version of reductionism (which may be called epistemological reductionism).

At this phase the author finds it interesting and important to find, via survey, which of the above mentioned versions of reductionism is more widely held by biologists, of various levels of

professionalism and specialty. Of course, this planned survey is not intended to "solve" the philosophical problem. However, it might yield interesting results for the "sociology of science" and it may provide 'backing' for the arguments brought above for the inclusion of biology vs. humanities dilemma in our teaching of biology.

The Objective of the Present Study

The objective of the present study was to develop methods and procedures, which will enable the identification and characterization of the personal version of reductionism held by the subject. The desired method sought was a structured interview in which the first questions would not appear directed to the biology vs. humanities dilemma. The last group of questions was planned to be directed to the focus of the evaluation topic. The rationale behind this approach was to enable the differentiation between interviewee's spontaneous position and his/her careful and formal presentation of the personal belief.

The Methodology

A structured interview was developed through trials and improvements by applying it to about twenty graduate biology students, from the department of animal physiology and biochemistry

of the Hebrew University of Jerusalem.

The interview included six written questions in a multiple choice format. The interviewee responded first to the six questions on the paper with no interruption. After completing this phase, the interviewer reviewed the responses with the interviewee, asking more questions about the interviewee's reasons and considerations. The oral discussion of this phase was less structured and oriented by arising needs for clarification. Only three sample questions will be presented below. After initial oral discussion of question 3 (below) the interviewer presented several concept maps to help sharpen the evaluation of the interviewee's position and beliefs.

Below are the sample questions.

Question 1

A person on trial for war crimes, who murdered many people, argues in defense that he had merely obeyed orders.

My opinion is:

- a) Man, in all situations is able and required to apply his free will and never agree to murder. Therefore, this aforementioned person must be blamed and severely punished.
- b) This person was not completely free in that war situation. Therefore, it is

hard to blame him and his punishment should be considered accordingly.

- c) "Free will" is an illusion. Man always behaves automatically by conditioned responses. "Blaming" is, therefore, an irrelevant term. For the sake of society, he should be severely penalized as a warning to others.

- d) Other than the above.

Question 2

A dying man wrote a will in which he bequeathed all his wealth to a woman who helped him during his last few months of life. His children challenged the validity of the will arguing that their father was under emotional duress.

My opinion is:

- a) Man is always free, therefore, we must honor his free will as expressed in his written will.
- b) Indeed, man has free will but there are certain situations in which man's free will is partially suppressed. This case should be analyzed accordingly.
- c) "Free will" is an illusion. Man is always influenced in a way that determines his moves. Therefore, man's last will should always be considered invalid and the Law should dictate who inherits a person's wealth.

Question 3

A cow is to be slaughtered and its meat sold. In many countries there is a public pressure to institute laws which would compel slaughter houses to use methods which would yield almost no suffering to the animal.

My opinion is:

- As long as the cow is alive it has a soul that feels and suffers, like we do. Thus, we should choose slaughtering methods that would not inflict suffering.
- Since an animal is merely a physico-chemical system, it cannot have any feelings (molecules do not have feelings). However, we should avoid cruel methods only in order to educate ourselves to be considerate.
- It is true that an animal is merely a physico-chemical system, yet, this system when disturbed (disequilibrated) may feel pain. Therefore we should cause no suffering to this physico-chemical system, called cow.
- Since an animal is merely a physico-chemical system, it cannot have any feelings. "Animal suffering" is an illusion created by people. The only criterion for choosing a method of slaughtering is efficiency.

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After oral initial discussion of Question 3 the interviewee was shown Map 1. (Figure 4) The interviewer read all the propositions on the map to the interviewee and then asked him if he/she agreed to the map content. Then the interviewer added to the map the concept "pain feeling" (in the dotted line frame) and asked what was that

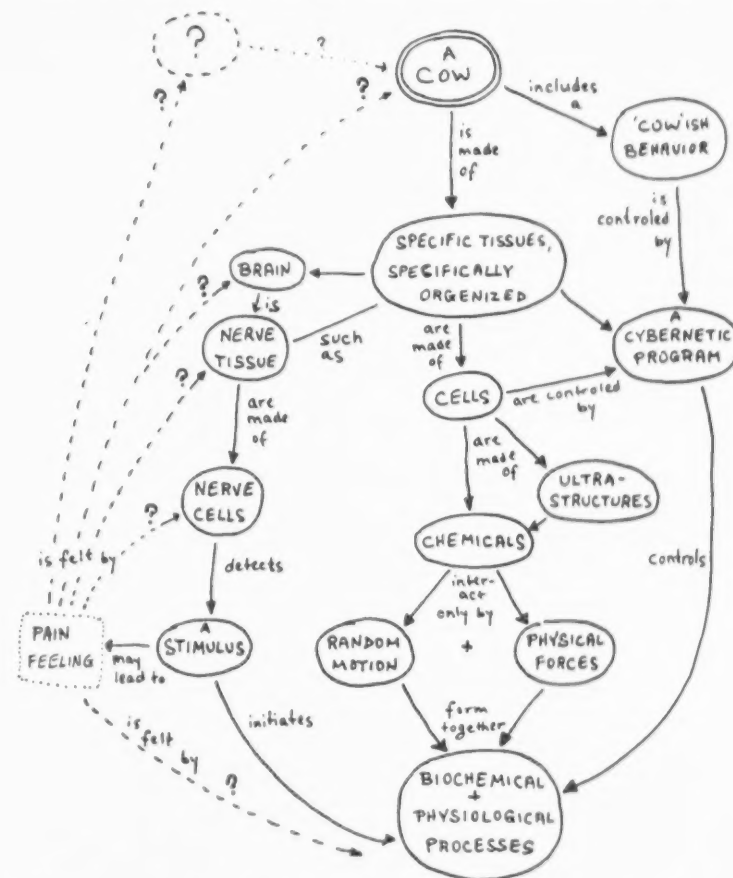


Figure 4. Map 1: A reductionist representation of "cow."

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thing that "feels" the pain. Dotted arrows were added by the interviewer to the map and the following questions were asked: Is it the chemicals themselves that feel the pain? Is it the individual nerve cells? Is it the nerve tissue or the whole brain? Is it the wholeness of the cow? Each of these levels of organization is reducible to its chemical constituencies, so so aren't we ultimately getting to claim that chemicals "feel"? Might it be that something of the cow, which is not made of chemicals, "feels" the pain?

After discussing Map 1 the interviewee was shown Map 2 (Figure 5) that was similar to map 1 but on this time the terms "cow" and "cowish behavior" was replaced by the terms "Man" and "human behavior". The interviewee was asked whether he felt comfortable with this representation of man, or maybe he preferred the (humanist) representation of Map 3 (Figure 6). The interviewer asks if these two maps contradicted each other, and if yes whether they could be reconciled, and how. The interviewer set at this point Maps 1, 2 and 3, side by side, and asked the interviewee to use as much as he could of the maps to show the process by which "a person decides not to inflict pain onto a cow."

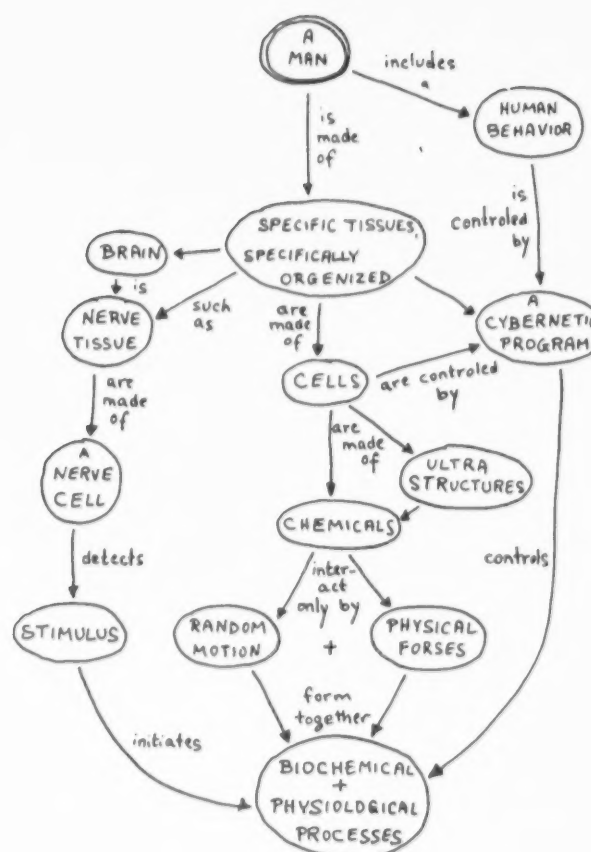


Figure 5. Map 2: A reductionist representation of man.

As an additional prop, Map 4, (Figure 7) was shown to the interviewee and the questions asked were whether the interviewee found it as meaningful to read the sentence A to A as to read it B to B. If the answer was yes the last question was what was the source of the demand "...shoud not inflict pain..."?



Figure 6. Map 3: A humanist representation of man.

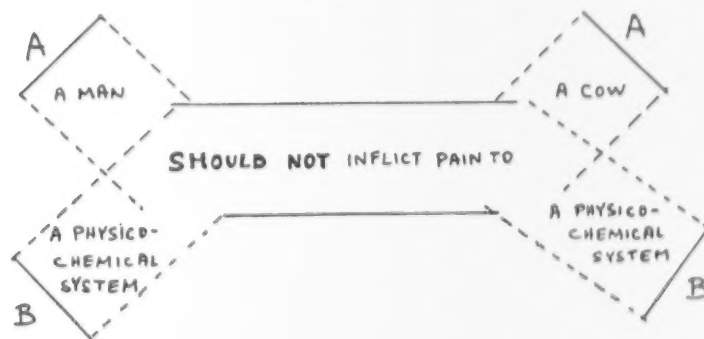


Figure 7. Alternative representation of a value statement.

First Findings About the Methodologies

It was not intended to present in this paper any survey results. The described interview method seems to provide the ability to identify and differentiate between different positions with regard to the humanism vs. biology dilemma. Beside the two aforementioned versions of the reductionist paradigm it was possible to identify cases of unawareness and misunderstanding of the very nature of the presented dilemma. In such cases it seemed possible to characterize typical misunderstandings and consequent inconsistency. The intention of the authors is to apply this methodology in a wide scale survey.

References

- Brumby, M. (1979). "Problems in learning the concept of natural selection," *Journal of Biological Education*, 13:119-122.
- Churchland, P. S. (1986). *Neurophilosophy: Toward a Unified Science of the Mind-Brain*. MIT Press, Cambridge, Mass.
- Driver, R. and Easley, J. (1978). "Pupils and paradigms: A review of literature related to concept development in adolescent science students." *Studies in Science Education*, 5:61-84.

- Kargbo, D. B., Hobbs, E. D. and Erickson, G. L.
(1980). "Children's beliefs about inherited characteristics." Journal of Biological Education, 19:137-146.
- Kuhn, T. S. (1970). The Structure of Scientific Revolutions. Second edition, Chicago: University of Chicago Press.
- Novak, J. D. (1977). A Theory of Education. Ithaca, N.Y.: Cornell University Press.
- Nussbaum, J. (1983). "Conceptual Change: The lesson to be made from the history and philosophy of science." In the proceedings of the International Seminar on "Misconception in Science and Mathematics" held at Cornell University, June 1983. Ithaca, N.Y.
- Nussbaum, J. (1985). "The particulate nature of gaseous," in Driver, R., Guesne, E. and Erickson, G. L. (Eds.), Children's Ideas in Science. Open University Press, Milton Keynes and Philadelphia.
- Schwab, J. J. (1964). "Structure of the disciplines: Meanings and Significances," in Ford, G. W. and Pugno, L. (Eds.), The Structure of Knowledge and the Curriculum. Chicago: Rand McNally.

Learning Science through Experiential Software

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Introduction

The past decade has seen a considerable body of research into the way in which children learn science and into the models of teaching employed by teachers. Driver et al(1985) and Osborne & Freyberg(1985) have summarised much of this work. The research emphasises the need for children to be regarded as active and purposeful learners who engage in a dynamic process of construction and reconstruction of the personal concepts which they use to understand science. It has been proposed that children progress in this way from a set of naive concepts in science which diSessa(1985) calls "pre-science" and Osborne and Freyberg call "children's science", to the accepted scientific world view.

It is claimed that this progression to a mature scientific perspective is critically dependent on an experiential approach to teaching which gives children ample opportunity to develop concepts in a supportive fashion. A constructivist view of learning such as this contrasts with the implicit model of learning which forms the basis of much traditional science teaching. This conventional model, outlined by Renner(1982), assumes a simple three phase sequence: formal presentation of prescribed information by teacher exposition, verification of the information by

closed practical work and practice of material presented in the first two phases through written exercises

The majority of software produced for microcomputers in the past five years is based on this 'conventional' view of the process of teaching and learning science. Since most of it is designed by teachers who hold this model, this is perhaps not surprising. In common with many other educational materials, much software fails to make explicit the learning model inherent to the product and the user is left in the position of guessing at how it should be used. The term 'electronic blackboard' which is often used to describe some software packages is notable in that it views the software and technology as merely a means of enhancing the demonstration of prescribed information by teacher exposition. The software is viewed as an aid to the normal traditional methods of science teaching providing interactive animated displays where the parameters can be varied. However almost always this is done by teacher demonstration and children are provided with little significant opportunity to explore and test their models of the physical reality.

A constructivist approach to computer software

Kemmis et al(1977) have made a notable attempt to categorise the learning experiences provided by computer assisted learning(CAL). They viewed the experiences as essentially one of four types

- Instructional
- Revelatory
- Conjectural
- Emancipatory

Instructional software relies heavily on exposition and reinforcement techniques of 'drill and skill'. Its roots lie in the psychology of Skinner and its notable weakness is that it has practically no ability to respond to variations in the learner. Its model of the learner is fixed and inflexible and although it provides valuable reinforcement practice for basic skills of reading instruments etc, it can hardly be said to provide meaningful learning as its ability to explain and adapt is far too often limited by the simplistic assumptions inherent to the design and the current limitations of the

technology. Such software is more consistent with a view of education which regards it as a process of training *in the skills and methods* of the discipline rather than an *education in* science which seeks to develop understanding.

Revelatory software in science is substantially represented by a large number of simulations. A simulation of the operation of a nuclear reactor is a typical example. The user will be able to vary the coolant rate or the depth of the graphite rods used as a moderator. This provides the learner with a valuable opportunity to explore a model of an object that is not available in the classroom. The function of this is to 'reveal' to the learner the behaviour of the system and allow them to develop an understanding of the model. However, the model is fixed, predetermined and often not visibly transparent. The learner is forced into the position of applying a heuristic approach to build an understanding and, unless the package is particularly appealing, may often lack motivation. This software only really has advantages from a constructivist perspective when the learner is asked to use it to test their hypothesis as to the behaviour of the system. The conflict between the predicted behaviour and the observed behaviour then allows the user to reflect and evaluate their conceptions of the underlying science.

When used in this mode, the software is essentially becoming conjectural which allows the user to test their hypotheses against reality and observe the effect of varying parameters. It is only this type of software that offers any possibility of conceptual conflict, an essential mechanism of change from the learners alternative concepts to an internalisation of the scientific model. Included within this category should be the wide range of software available for performing experimentation. Although the software itself is not inherently conjectural, the scientific activity it facilitates is. As Thornton (1987) argues that 'Laboratories using microcomputer based laboratory (MBL) tools allow students to build on their experiences like those in their everyday interaction with the world, but also allow them, through immediate feedback of data in useable forms, to move away from misconceptions towards a deeper scientific understanding of these experiences.'

Kemmis' final category refers to that wide range of general purpose software that is essentially designed to extend and enhance the capabilities of the user. In science education, software packages that perform data analysis and plot graphs are probably the most extensive in this area. The relative high cost of microcomputers

has meant that children do not have frequent access to the 'wordprocessors of the science laboratory'. However, there is a substantive argument that, just as wordprocessors have transformed many adults attitude to the act of writing, liberating them from the fear of error and laboriousness of endless redrafts and allowing them to polish the product to an acceptable form, so may such tools provide children with an opportunity to produce printed results of high quality, raising their self esteem, motivation and confidence. Since motivation is seen as a central feature of learning from the constructivist perspective (Hewson & Hewson, Osborne & Wittrock 1985), the contribution of educational software to such schemes should not be ignored.

What potential does educational software have for meaningful learning in science? We believe it is possible to assess the relevance of educational software to the learning of science which are consistent with such an approach by the use of the following criteria. As such they represent a schema for evaluating science software.

- (1) Educational software should be primarily orientated towards the representation and development of concepts. Topics for software should be chosen from the standpoint of whether they can provide a good context for promoting conceptual development. An essential requisite is that these should provide an experiential basis for learning, developing conflict between the child's pre-existing concepts and the model presented by the software.
- (2) In common with other recent curriculum materials, software should not assume that the child has no scientific conception of reality themselves.
- (3) Software should provide a context which is relevant to the way in which children think about the real world. There should be a synergy between the representations and interactions provided by the software and children's perceptions of the real world.
- (4) Children should be able to construct their own personal representation of reality in the software environment. This implies that children should be able to modify and extend the software in such a way that it accords with their own current concepts.

- (5) It should be possible for the software to support alternative concepts. This is essential if children are going to use software to compare concepts and reconcile conflicts between alternative concepts.

It is unlikely that any individual program will satisfy all criteria but software that is consistent with these aims is in essence conjectural allowing children to construct and manipulate a model of reality and test its behaviour against their expectations. It is possible to identify two main strands of computer assisted learning that offer the most significant potential for a 'constructivist' approach to learning. These are the activity of modelling and the use of software to provide idealised representations of reality or 'ideal worlds'.

Modelling as a constructivist activity

The process of modelling is one of the fundamental mechanisms of human thought. Marx (1984) highlights this in his statement that 'Man is a model making animal,' and that

'Science makes extended use of models. The history of science could not be told without mentioning celestial spheres, rigid bodies, indivisible atoms, elastic lines of force, the vibrating ether, the atomic planetary system, the valence hook, the double helix, corpuscle-wave dualism.'

The act of understanding often involves the development of a complex schema that represents the perceived external reality. Models are developed through a process of critical evaluation and review and this leads to the typical understanding of the mature adult. Programming and system simulation provide one of the most valuable tools available to the scientist to model physical systems. Modelling languages such as *Simula* and *Dynamo* have been widely available in higher education for the past decade but such work has had minimal impact on the secondary school curriculum. The most notable development is the Dynamic Modelling System (Ogborn J. & Wong D., 1984) and the Cellular Modelling System (Holland and Ogborn, 1987). Both of these allow children to model simple systems using a formalism of the BASIC programming language.

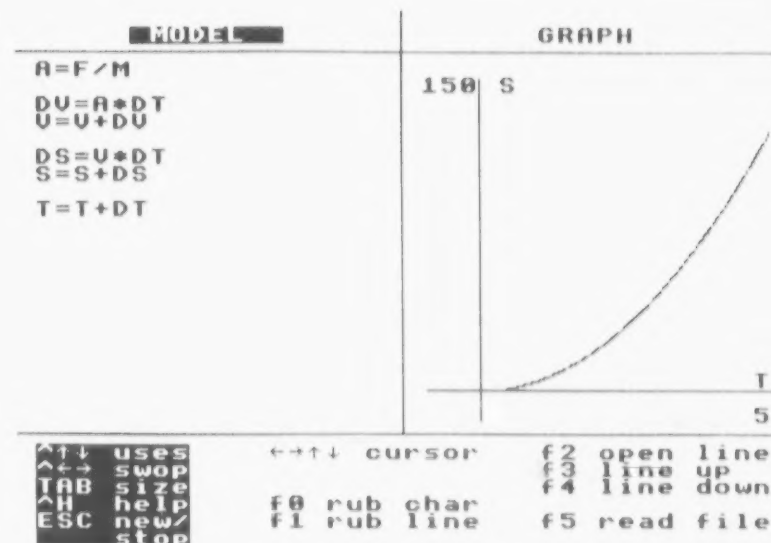


Fig 1: Typical screen from Dynamic Modelling System.

With this system, the user is presented with two pads which can be used to construct the model and display its behaviour graphically. A model to investigate the movement of an object in a gravitational field would be

Gravitational Force	$F = -10$
Newton II	$A = F/M$
Velocity from acceleration	$dV = A * dt$ $V = V + dV$
Displacement from velocity	$dS = V * dt$ $S = S + dS$
Clock	$T = T + dT$

In addition, the user has to define the initial values used by the model by changing the pad to the title 'Values'. Once these are defined, the axes of the graph and the range of values must be specified and the model can then be run.

The activity of modelling includes the expression of the model, on paper or on a computer, using a symbolic formalism. The model is then evaluated by execution and examination of the graphical results and comparison with reality. The results shown in Fig 1 represent the idealised result where air resistance is minimal or zero. The model can easily be adapted to include the effects of air resistance by changing the force equation to

$$F = -10 + K \cdot V^2$$

allowing the child to construct a more sophisticated model than is possible on many undergraduate courses. Previous knowledge and new experiences are built on to 'construct an understanding of reality which is simulated on the computer. Modelling languages provide a new means for expressing thought and articulating concepts that are less dependent on a comprehensive understanding of mathematics. This is one of the fundamental attractions of computing for adults as it provides a new tool for expressing ideas. This is aptly reflected in the statement

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by Wittgenstein(1961) that 'The limits of my language are the limits of my world.' Modelling languages provide another language for understanding the world and the purpose of modelling is to provide insight. As yet, it has not been extensively used in schools. But is not the science we teach, that which we can teach? Science educators are opportunist in their approach to the teaching of science making a virtue out of necessity using available technology. The development of courses in chaos and non-linear dynamics in higher education is primarily due to the availability of microcomputer modelling tools. The arrival of the cheap microcomputer with its 'user-friendly' software necessitates a re-evaluation of our methods with a view to the contribution such materials can make to a constructivist pedagogy.

This modelling system is still dependent on an appreciation of stepwise algorithmic approaches to problem solving and the formalism of the BASIC programming language. The evidence is that this is not easily understood by children. However modelling languages such as *Stella* and the futuristic alternate reality kit(O'Shea & Randall Smith, 1987) that make use of iconic symbols to present a more visual model show greater potential for expressing and constructing conceptual models. The graphical representation of *Stella* emphasises the structural connectivity and symmetry of the model. It also provides a rich visual syntax to visually define such concepts as links and flows and is similar in this respect to the concept maps of Novak & Gowin(1986).

Programming languages also have a role to play in providing a means to construct simple models of physical environments. LOGO is one whose use has been argued for extensively, particularly in mathematics education(Papert, 1980; Harvey, 1982; Abelson & Di Sessa, 1980;). Only a small amount has been written about its potential in science education and this is restricted to physics(Hurley, 1985; Lough, 1986, Morecroft, 1986). Simple models can be created with the following procedures

```

TO MOVE
FORWARD 1
MOVE
END

```

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Typing MOVE sets the turtle in motion across the screen simulating an object moving with no resultant force acting on it. The object can be made to accelerate by altering the program as follows

```
TO ACCELERATE
MAKE "STEP 0
MOVE
END
```

```
TO MOVE
MAKE "STEP :STEP + 1
FORWARD :STEP
MOVE
END
```

In this example the 'turtle moves forward a distance given by the variable parameter :STEP. Typing ACCELERATE will cause the turtle to accelerate constantly across the screen. Circular motion can be simulated with the simple program

```
TO CIRCLE
REPEAT 360 [ FORWARD 1 RIGHT 1]
END
```

The last example makes the important point that to move in a circle, the turtle must turn towards the right and the centre of the circle. Hence the force must act towards the centre. These examples can be extended to simulate projectile motion, free fall and simple harmonic motion. To the mature physicist they may seem trivial but to the child, they may be a means of access, a point at which their minds and imaginations are able to engage with the world being simulated on the screen.

LOGO has also been used for developing microworlds in which children can explore scientific concepts. diSessa et al (1982) produced a microworld in which children can explore dynamics using a computational object called a 'dynaturtle' which obeyed Newtonian mechanics. Children were invited to use a 'kick' primitive which gave the turtle an impulsive force in a specified direction and compare the actual behaviour with their hypothesised predictions. The conflict

generated led the children to explore and reconstruct their concept of force. Further work in developing LOGO microworlds is currently in progress and is described by Squires (1987). In essence, this work is based on the idea of a 'field turtle' which is concerned with the concept of action at a distance and provides children with an opportunity of exploring the behaviour of such objects.

Ideal worlds

The models that scientists use to think about the real world are not obvious - Newtonian dynamics as a way of describing and thinking about the manner in which objects move is a well known and documented example. Scientists use abstractions, ideas and concepts which are inventions of science. There is no implicit reason why children should know about them or use them as methods to achieve understanding. However they are powerful and useful ways of looking at the world and we maintain that the primary task for science education is to devise ways of making these scientific ideas accessible and meaningful to children.

Why not represent these ideal conceptualisations of the way nature works on a computer? - not just as a simulation of a defined process or system but as a clearly articulated representation of scientific concepts. In this way we propose that it is possible to use computers to provide experiential environments for children to observe the consequences of the application of accepted scientific ideas.

There is considerable evidence that children employ a range of concepts to understand electric current and that they typically have difficulty in perceiving and using the classic model of current flow in simple d.c. circuits (Shipstone 1984). *Circuits* (James et al, 1986) attempts to provide an ideal environment through software concerned with the exploration of series and parallel circuits consisting of cells, bulbs and a switch. The software presents children with various circuits which have a fault which prevents some or all of the bulbs in the circuit from lighting. By moving a cursor around the circuit the children can add and delete components using a simple menu system. It is possible for a teacher to specify the order in which the children are presented with circuits and for a teacher to design circuits which will be used by the software. In this way the teacher can "customise" the learning environment which the children are given.

The cells which the children can use when they operate the software are never "flat" and have zero internal resistance, the connecting wires have zero resistance and equally rated bulbs give a uniform brightness. In this way the children are protected from the experimental "noise" - e.g. loose connections, the idiosyncratic behaviour of the bulbs, and flat cells - which we suggest often hinders their perception of the way in which the behaviour of simple circuits can be understood.

The design of this software raises some interesting questions concerned with the relationship of the use of this type of software and to experimental work in the laboratory. For example, in an attempt to focus the children's attention on the BASIC physics involved, the representation of the brightness of the bulbs is deliberately stylised in terms of a number of "spokes" surrounding a bulb. This is obviously a simplistic representation, taking no account of the variation in brightness of a bulb with temperature, but we maintain that this is understandable by children and consistent with the concepts on which the software is based. It is proposed that children may be able to interpret the results of experimental work in a far more meaningful way after they have viewed the behaviour of simple circuits in the ideal fashion outlined above.

Work on the alternative frameworks that children employ to understand dynamics is well known and documented (Gilbert & Watts 1983). In essence, it appears that children find it very difficult to conceive of a world in which motion is governed by Newtonian dynamics. In particular there is a commonly held belief that the action of a force is to cause a change in displacement rather than a change in velocity and that left alone a moving body will eventually come to rest without the application of any external force. *World of Newton* (Ogborn, 1986) provides a computer based dynamics laboratory in which impulsive forces can be applied to an object which will then move around the computer screen. The object will move in a Newtonian fashion in an environment in which friction can be turned on or off, the mass of the object can be changed at will and in which gravity can be varied from zero through a set of discrete values to a maximum. It is possible to trace the path that the object follows and to superimpose a grid on the screen. An example of the motion of the object is shown in Figure 2.



Figure 2 An example of the motion of an object in *World of Newton*

This software could provide an environment in which the child can develop a tacit and intuitive understanding of Newtonian dynamics. Without the internalisation of an alternative model of dynamics to the commonly held Aristotelian conception, there is little chance that they will perceive a conflict between their views and the accepted scientific model. We maintain that similar learning outcomes to those proposed in association with the use of *Circuits* may be possible here.

Conclusion

It is our proposition that the use of appropriately designed computer software can provide unique experiences and insights of scientific phenomena. These may provide an opportunity for children to:

- i) construct their own models of reality in a supportive environment;
- ii) test and evaluate these mental models;
- iii) compare and contrast their models with commonly accepted scientific models

Consideration of the potential for software to give the children these opportunities has significant implications for the design and evaluation of science educational software which have not been widely recognised to date. If computer based materials are to be of genuine use in future science education, the design of the materials must reflect an experiential approach to the nature of learning which is

entirely consistent and supportive with a constructivist approach to learning in science.

References

- Abelson H. & diSessa A. (1980) *Turtle Geometry: The Computer as a Medium for exploring Mathematics*. MIT Press, Cambridge, Massachusetts.
- diSessa A. & White B. (1982) Learning Physics with a dynaturtle. *Byte* 7, 324
- diSessa A. (1985) *Computers and experience in learning science* in LOGO 85 Theoretical Papers (1) Massachusetts Institute of Technology, Massachusetts.
- Driver R., Guesne E. and Tiberghien A.(eds) (1985) *Children's Ideas in Science*. Open University Press. Milton Keynes.
- Gilbert J.K. & Watts D.M. Concepts, Misconceptions and Alternative Conceptions. Changing Perspectives in Science Education. *Studies in Science Education*, 10, 61 -98.
- Harvey B. (1982) Why Logo? *Byte* 7, 163 -172
- Hewson P.W. & Hewson M.G.(1984) The Role of Conceptual Conflict in Conceptual Change and the design of Science Instruction. *Instructional Science*, 13, 1- 13
- Holland D. & Ogborn J. (1987) *The Cellular Modelling System*. Longmans. Harlow. England
- Hurley J.P (1985) *Logo Physics*. Holt, Rinehart & Winston. New York.
- James J., Christie M. & Wood J. (1986) *Circuits*. Longman Microsoftware. Harlow. Essex
- Kemmis S., Atkin R. & Wright E. (1977) *How do Students Learn? Working paper on Computer Assisted Learning*: UNCAL Evaluation Studies. Occasional Publications 5. Centre for Applied Research in Education. Norwich.
- Lough T. (1986) Logo & Physics. *The Physics Teacher*. Jan, 13-19
- Marx G. (1984) *Games Nature Plays*. National Centre for Educational Technology. Hungary.
- Morecroft L. (1986) *A Relative Motion Microworld(MA Thesis)* . Laboratory for Computer Science, Report 347. Massachusetts: Massachusetts Institute of Technology
- Novak D. & Gowin R. (1986) *Learning How to Learn*. Cambridge University Press
- O'Shea T. & Randall Smith (1987) *Violating the Laws of Nature-experiments in understanding physics by exploring alternate realities*. Paper presented at CAL 87, Strathclyde University. April 1987.
- Ogborn J. & Wong D. A (1984) A Microcomputer Dynamic Modelling System. *Physics Education*, 19, 135-142.
- Ogborn J. (1986) *World of Newton*. Longman Microsoftware. Harlow. Essex
- Osborne R. & Fryberg P. (1985) *Learning in Science: the Implications of Children's Science*. Heinemann. London
- Osborne R. & Wittrock G. (1985) The Generative Learning Model and its Implications for Science Education. *Studies in Science Education*, 12, 59 - 87
- Papert S. (1980) *Mindstorms*. Harvester Press. Brighton.
- Renner J. (1982) 'The power of purpose' *Science Education* , 66,709-16

Shipstone D.M. A study of children's understanding of electricity in simple D.C. circuits. *European Journal of Science Education*, 6, 185 - 98

Squires D. (1987) Providing Computer based experience for learning Physics. *Physics Education* 22, 239-243

Stella (1986) High Performance Systems, Inc, 13 Dartmouth College Highway, Lyme, New Hampshire 03678. U.S.A.

Thornton R. (1987) Tools for Scientific thinking-microcomputer based laboratories for physics teaching. *Physics Education* 22, 230-238.

Wittgenstein L.(1961) *Tractatus Logico-Philosophicus*. Routledge. London.

Patterns of Misunderstanding: An Integrative Model of
Misconceptions in Science, Math, and Programming

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Recent research in the learning of physics, mathematics, and programming tells a tale of similarity within diversity. Despite significant differences among these domains, patterns of misunderstanding appear in novices -- and sometimes even in experts -- that seem in many ways to reflect analogous underlying difficulties. In physics, for example, students typically solve problems by rote equation cranking. They first engage in a formulaic matching of the variables presented in the problem to equations and then perform standard algebraic transformations on the equations to solve for the unknowns (Chi, Glaser, & Rees, 1982; Chi, Feltovich, & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980; White & Horwitz, 1987). Missing is the sense of the "deep structure" of the problem organized around key interpretive concepts such as conservation of energy.

In mathematics problem solving, one sees the same pattern of attention to surface similarities. Schoenfeld (1985) notes examples of students who characteristically perform meaningless calculations on a problem, with no attention to whether or not the particular approach is justified, or progress being made, instead invoking schema apparently based on such phenomena as recency or familiarity. In computer programming as well, "template-bound" coding with no apparent accompanying attention to the underlying mechanisms of the primitives is a common and persistent stumbling block (Perkins & Martin, 1986; Perkins, Martin, & Farady, 1986).

Another anomaly frequently seen across domains is the use of notational expressions that somehow violate the semantics. This occurs in math when students make errors of distributivity; for example, the square root of A plus B is said to equal the square root of A plus the square root of B. Now algebra refers to numbers -- numbers provide its semantics, so to speak -- and an effort to check the distributivity relation with numbers

would quickly disclose its error. In programming the same phenomenon occurs; one sees expressions such as "PRINT 5 *" (in BASIC) as an attempt to output a row of 5 stars on the screen (Perkins & Martin, 1986). Students often do not check such expressions against the semantics of the programming language by hand-executing the expression. In the sciences, students not uncommonly derive and report physically implausible or meaningless results -- negative speeds or masses, for instance -- because that is what the equation cranking has delivered.

In all these instances, it is as though the students have forgotten what the statements mean in terms of interpretive models -- numbers in the case of algebra, machine actions in the case of programming, physical quantities with certain constraints in the case of physics -- and instead write and manipulate expressions in ways that suit their hopes and intentions, unfettered by a constraining semantics.

A further problem exhibited by students can be characterized as an anthropomorphism or animism regarding major elements in the domain. Naive animistic concepts are commonplace in physics. For instance, sources of forces need to be agent-like things that can "push back," such as springs or springy substances; rigid substances are seen as having no way to push back (diSessa, 1983; Clement, 1987). One can argue that all objects are more or less springy, of course, but, beyond that, the existence of an equal and opposite reaction force does not require springiness. Likewise, in programming, many errors can be attributed to a conceptual "superbug" in which the computer "understands" the meaning and the intentions of the statements it processes (Pea, 1986). Thus, for example, given a variable name of LARGEST in a Pascal program, the computer will "know" to store the largest of a series of numbers it reads into that variable because it comprehends the semantic unit "largest" (Sleeman, 1986).

In sum, among a surfeit of student misunderstandings, there appear to be some strong similarities across the domains of physics, math, programming, and no doubt others as well. This observation raises a number of intriguing questions: Can one

characterize broadly parallel causes of these parallel misunderstandings? Moreover, in some degree, might the causes be not just parallel but identical -- crosscutting levels of knowledge that, because faulty in certain ways, undermine understanding in several domains at once? Such a stand would, of course, run counter to one current viewpoint that holds that expert performance is, by and large, domain specific. Finally, what educational implications would follow from identifying parallel and common causes?

In this article, we present a tentative attempt at an integrative model of misunderstandings in science, math, and programming, directed at answering these questions. First of all, we identify four levels of knowledge implicated in misunderstandings. In the first of these, which is domain specific, misunderstandings arise because of parallel causes in different domains. In the other three, which are to some extent crosscutting, misunderstandings arise in different domains because of the very same causes. Second, we identify a few typical patterns or syndromes of understanding -- "gestalts" that arise frequently, involving several of the levels. We suggest that misunderstandings have causes at multiple levels that interlock to form these distinctive gestalts. Finally, we argue in light of this framework that education characteristically neglects large parts of certain levels of knowledge and virtually all of certain others. Better education calls for more thorough attention to each and every level.

Four Frames for Understanding a Paradigm

Adapting a term from Thomas Kuhn (1962), we refer to the systems of thought that we would like students to understand as paradigms. The term is intended in a more restricted sense than that of Kuhn, naming the limited systems such as beginning algebra, elementary Newtonian mechanisms, elementary programming in BASIC, and so on, that students face. Nonetheless, a paradigm even of limited scope in the ideal has many aspects. We find it heuristic to characterize deep understanding of a paradigm as

involving a matter of four interlocked levels of knowledge named the content frame, the problem-solving frame, the epistemic frame, and the inquiry frame. The term "frame" simply serves as a reminder that each of these is a system of schemata internally coherent and partially independent of the other frames.

In brief, the four frames are as follows:

- o Content frame. This contains the specific paradigm content at issue, for instance specific knowledge of Newtonian physics or programming in BASIC.
- o Problem-solving frame. This encompasses more general knowledge concerning problem management, generic problem solving heuristics, and the like. The problem-solving frame, in combination with knowledge from the content frame, facilitates solving conventional textbook problems.
- o Epistemic frame. This frame incorporates norms about the justification of claims, procedures, and knowledge systems. The soundness of the paradigm depends on how well the content frame matches up to the standards set by the epistemic frame.
- o Inquiry frame. This frame includes general patterns of thinking that work to extend and to challenge a paradigm. To put it another way, the inquiry frame is concerned with critical and creative thinking about paradigms, beyond the scope of normal textbook problems.

The four frames have been described in terms of what they should contain. But, of course, often these frames contain instead naive and reductive notions. Sometimes they may contain hardly any notions at all -- for instance, a student may have no idea what the epistemic foundations of a particular paradigm are, or how to deploy the paradigm in a spirit of inquiry.

It is easy to see that ideal versions of the four frames would contribute to a very sophisticated understanding of a

paradigm. However, one might question whether all four are relevant to our aspirations for students' understanding. Do not they go too far? Could not a student perfectly well evade the various misconceptions students evince without nearly so sophisticated an armamentum? Moreover, the frames other than the content frame have quite a general character; does not this analysis run counter to the current evidence that expertise is heavily rooted in domain-specific knowledge (e.g. Chase & Simon, 1973; Chi, Glaser, & Rees, 1982; Chi, Feltovich, & Glaser, 1981; Glaser, 1984; Newell & Simon, 1972; Schoenfeld & Herrmann, 1982)? For all these reasons, the four frames may appear to be an unlikely basis for a deeper look at the roots of students' misunderstandings.

Despite these concerns, however, we urge that the four frames play a fundamental role. We will argue that, contrary to appearances, evading misconceptions in any real sense requires the kinds of higher order sophistication represented by the non-content frames. The evidence on expertise notwithstanding, we will argue that understanding intrinsically involves domain-general considerations such as those articulated for the non-content frames.

A Radical Example

Before describing the four frames in more detail, we can begin on these arguments by discussing a single example to preview the general approach. As mentioned earlier, students commonly and inappropriately apply a principle of distributivity to the radical sign. For example, an algebra student may write:

$$\sqrt{A+B} = \sqrt{A} + \sqrt{B}$$

Now the key question is: Why has the student fallen into this misconception?

Thinking purely in terms of the content frame for elementary algebra, one might simply say that there is a gap in the student's knowledge base about algebra. The student does not happen to know that distributivity does not apply to the radical. The

student either believes the principle does apply, or, while uncertain, presumes that it does by explicit or tacit analogy with the distributivity of multiplication over division and of exponentiation over multiplication.

But can one really stop with the content frame? On the contrary, the circumstances suggest that procedures attributable to a general problem-solving frame play a role here. First of all, the uncertain student, who uses analogy to generate a rule, is deploying a general strategy, one that students use in many contexts. Without the analogical strategy, there would be no false rule to worry about; the student simply would not know what to do. Unfortunately, it seems that the students' problem-solving frame lacks a complementary strategy. A strong problem-solving frame for math, the hard sciences, and programming embodies a conservative strategy to filter out false analogies: All steps need grounding; when uncertain, check the soundness of an idea rather than just proceeding on speculation. A student lacking this conservative principle responds somehow -- anyhow -- in order to proceed with the problem (cf. Brown & VanLehn, 1980; VanLehn, 1981a).

Now let us consider whether there is a role for the epistemic frame in this example. Suppose the student feels uncertain about the distributivity rule yielded by analogy-making. What might the student's epistemic frame say that would encourage, or discourage, an effort to check the rule? Well, many students' epistemic frames seem to treat rules of a formal system like algebra rather like "rules of the game." Somewhere, someone made up or figured out the rules, which are basically to be learned, not checked. If one has to check, one asks the teacher or looks the rule up in a book. A very different and less reductive epistemology would recognize that any notational system, such as that of algebra, has a semantic basis that entails the rules. In the case of algebra, the semantic basis is real number arithmetic, and one can always check a proposed algebraic relation by testing it with numbers. A student with a strong sense that numbers provide the semantic foundation for algebra

is considerably more likely to see checking with numbers as a reasonable and rewarding course of action.

As to the inquiry frame, it must be plain that proceeding on speculation discloses no critical posture at all toward the paradigm and the (invalid) extension of it offered by the false distributivity rule. It is as though the student's tacit inquiry frame reads like this: Go by what you know; if you don't know, ask; if you can't ask, guess. In other words, "inquiry" takes the reductive form of interrogating official sources.

With this particular example reviewed, let us return to the first of the general questions raised earlier: Could not a student evade this misconception without help from the non-content frames? Well, of course a student could. The student might simply know by rote that the rule was false and hence not make the mistake. However, obviously this kind of escape from error does in itself not constitute understanding but simply skill with the rituals of algebra. To appreciate why there is a rule that might hold, but does not, the student must encompass more. The student must see how analogy motivates a certain rule; this understanding seems to implicate the problem-solving frame. The student must see how a check against real numbers invalidates the rule, and must appreciate that this not merely a ritualized way of checking expressions but rather just the right check to make -- because the very rationale for the rule structure of algebra is inherited from the real numbers. This implicates the semantic frame. Perhaps the student could understand all this without a strong inquiry frame, but at least the other two seem necessary.

Now consider the second question raised earlier: How does all this jibe with the research on expertise that argues that expertise is highly domain specific (e.g. Chase & Simon, 1973; Chi, Glaser, & Rees, 1982; Chi, Feltovich, & Glaser, 1981; Glaser, 1984; Newell & Simon, 1972; Schoenfeld & Herrmann, 1982). In reality, there is no conflict. First of all, the dependency of expertise on domain-specific knowledge (the content frame) is part of the present model. For instance, the student

is in no position to check or even generate the false radical rule unless the student has the beginnings of an acquaintance with algebra and quite a good sense of number. Secondly, the dependency on domain-specific knowledge in no way entails that there are not other more crosscutting knowledge systems at work -- the problem-solving, epistemic, and inquiry frames. It is not from the higher order frames alone, or the content-frame alone, that understanding emerges, but from their confluence.

Thirdly, and perhaps most important, expertise and understanding are not the same thing, at least if we take expertise in a narrow sense. It is perfectly possible to be a facile handler of textbook algebra problems without really understanding algebra; one has merely become very good at the rituals of algebra. Likewise, it is perfectly possible to understand quite well the grounds of algebra, but to proceed with algebra problems in a halting and roundabout way because one has not yet acquired the "compiled" contextualized procedural knowledge characteristic of expertise (cf. Anderson, 1983).

With these general points in mind, we turn to discussing the four frames in more detail.

The Content Frame

As mentioned earlier, the content frame encompasses knowledge having to do with the particulars of a paradigm. At the heart of a content frame lies the core concepts that characterize the paradigm. In the case of elementary Newtonian physics, for example, these would include such notions as force, mass, velocity, and acceleration. In the case of elementary programming, the core concepts would include the notions of variable, expression, assignment statements, loops, and so on. In the case of elementary algebra, concepts like variable, expression, equation, solution, and so on, would occupy the core. Also central to the paradigm is what might be called "mapping schemes" that associate the core concepts with referents. Thus, for example, one has to associate mass or acceleration with the right sorts of phenomena in the world in order to handle elementary physics effectively.

The content frame can be faulty in a number of ways. We discuss several to illustrate.

Naive, underdifferentiated, and malprioritized concepts.

As has been widely recognized, students do not approach paradigms new to them with empty minds. They bring preconceptions that often rival and override those of the paradigm itself. For some examples from physics, impetus-like conceptions of motion have been found in students of physics in numerous experiments (e.g. Clement, 1982; Clement, 1983; McCloskey, 1983; Ranney, 1987). Underdifferentiation between neighboring concepts such as heat and temperature is commonplace -- and indeed was a problem in the history of physics (Wiser & Carey, 1983). DiSessa (1983) has pointed out that sometimes the problem can be one not so much of mistaken concepts as malprioritized concepts. For example, to novices rigidity is as salient a property of matter as springiness, whereas for a physicist, springiness plays a far-reaching explanatory role while rigidity is a never-achieved limiting case of little interest.

Inert knowledge. Freshly acquired knowledge is likely to be inert, particularly if the knowledge was obtained in a didactic fashion (Bransford, Franks, Vye, & Sherwood, 1986). To offer an example from programming, experiments with novice programmers reported by Perkins, Martin, and Farady (1986) and Perkins and Martin (1986) revealed that a high percentage of their knowledge was inert: While students commonly evinced for lack of a relevant knowledge structure, simple nonspecific prompts often led to them recovering the relevant knowledge and proceeding correctly. In other words, they possessed the knowledge but did not initially retrieve it.

Sometimes it is the everyday knowledge rather than the new knowledge that is inert. For an example from physics, youngsters who have learned that thermometers measure temperature may lose track of the connection between what the thermometer measures by technical means and their own sense of hot and cold. They will expect thermometer readings to add to yield twice the temperature when two cups of water at the same temperature are combined,

never considering their own common-sense knowledge that the "feel" of the water will be the same (Strauss, 1986).

Garbled knowledge. Inertness aside, newly acquired knowledge commonly gets mixed up in various ways as well. To mention a few examples, beginning students of physics may recognize friction as a force operative when one object is moving against another, but not when the object is stationary against the other (Roth & Chaiklin, 1987). Students may attribute both impinging force and reaction force to the same object, rather than the reaction force to the "supporting" object (Anzai & Yokoyama, 1984). In programming, students may import elements from one command into the midst of another (Perkins & Martin, 1986). In arithmetic, students attempt diverse variations on the rules of arithmetic in order to "repair" the situation when they do not quite know what to do (Brown & VanLehn, 1980; VanLehn, 1981a).

Formulaic thinking. One common tactic students develop for coping with the flood of new information as they encounter a paradigm is to develop template-like responses to particular cases, without grasping the "deep structure" of the paradigm. Their formulaic thinking shows up when, faced with a somewhat new situation, they respond in a stereotyped way. For example, one student of programming who had recently studied FOR-NEXT loops felt that a problem really ought to include one and quite correctly incorporated a FOR-NEXT loop of the form FOR N = 1 to 1 (Perkins & Martin, 1986). Similarly, students in arithmetic commonly develop stereotyped responses to key terms in word problems -- "less" means subtract, "times" means multiply, and so on.

Considerations like those raised above help us to understand why students display the difficulties that they do. Naive concepts naturally will rival the new ones out of the textbook. Formulaic thinking is a reasonable although limited coping strategy. A recently acquired knowledge base is likely to contain considerable garbled and inert knowledge. Yet there is more to puzzle about than these considerations in themselves explain. With the problem-solving frame in mind, why do students

not struggle harder to retrieve or work around their inert knowledge and to disentangle their garbled knowledge? With the epistemic frame in mind, why do students often cling stubbornly to naive concepts even when they have been shown demonstrations and given arguments that reveal profound difficulties in those naive concepts? With the inquiry frame in mind, why do students not display a more critical and creative spirit in questioning their first construals?

The import of these questions is straightforward. Although the misconceptions students manifest certainly involve the content frame, the misconceptions appear to be exacerbated by weaknesses in the other frames. We turn now to examining the character of some of these weaknesses.

The Problem-Solving Frame

Ideally, the problem solving frame incorporates metacognitive knowledge that helps one direct the problem-solving process. It includes heuristics such as breaking problems down into manageable parts, regulating time spent on any one solution path, seeking alternative paths when appropriate, and so on (Polya, 1954; Schoenfeld, 1980, 1985). It also includes supportive beliefs about and attitudes toward the problem-solving process. Unfortunately, however, the novice's problem-solving frame may instead be stocked with a number of marginally productive or counterproductive strategies, attitudes, and beliefs. Here are some cases in point.

Trial and error. Undisciplined trial and error methods are surprisingly common. In mathematics, Schoenfeld (1985) cites the example of college freshmen (having completed a semester of college calculus) who, given a task of geometric construction, guessed incorrectly a solution within a minute of reading the problem, kept guessing until they came up with a reasonable solution on the third conjecture, but were unable to say why the solution worked, offering only, "It just does."

Perseveration and quitting. Another common hazard is perseveration with an approach that is yielding no real progress

on the problem. Again, Schoenfeld (1985) describes examples of this behavior. Quitting is the flip side of perseveration. The behavior of sizing up a math problem and quitting at once if no obvious path to a solution presents itself is commonly remarked. In programming as well, we have observed both perseveration in an approach and the tendency to quit (Perkins, Hancock, Hobbs, Martin, & Simmons, 1986).

Proceeding on a guess. As discussed in the case of the radical, students who cannot recall just what the rule is commonly make plausible conjectures and then proceed on that basis, doing nothing to test their conjectures. They thus reason by analogy to generate a possibility -- an intelligent move -- but fail to deploy any kind of filter to check their possibility.

Equation cranking. One of the most commonly observed characteristics of novice problem solvers is an "equation cranking" approach, whereby the students note what needs to be derived, seek equations that yield those results, and work backward toward the givens until they find a chain of equations that will bridge from givens to solution (cf. Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Rees, 1982; Larkin, McDermott, Simon, & Simon, 1980; White & Horwitz, 1987). In part, this pattern reflects content frame difficulties; novices lack the insight into the domain to assemble qualitative models as a basis for reasoning forward from givens to unknowns, the more typical expert path. At the same time, one would hope that part of the ideal problem-solving frame would be a disposition to seek such paths, using the limited knowledge at one's disposal to understand qualitatively the problem as best one could.

The Epistemic Frame

The epistemic frame focuses on general norms having to do with the grounding of the concepts and constraints in a paradigm. For example, in physics, one ought to have a theory that is consistent with the evidence. Also, one's intuitive notions of the constructs involved should match one's formal manipulation of those concepts using logic and mathematics. In contrast with

many areas of life, the hard sciences, mathematics, and programming demand extraordinarily high standards of coherence between models and what they describe and within models themselves. Unfortunately, most students have not developed the hypersensitivity to coherence required by these technical domains. Among the weaknesses in the novice's epistemic frame are these.

Intuitions mask contrary observation. Expectations based on naive intuitions and prior practice not uncommonly actually modify what one sees or recollects. For example, diSessa (1983) notes that people typically analyze the question, "How would blocking the intake of a vacuum cleaner affect the sound of the motor," by applying an intuitive concept (in diSessa's terms, a p-prim or phenomenological primitive) in which greater resistance means greater strain, implying a lower-pitched sound. In fact, the pitch goes up, but diSessa's interview subjects frequently reported remembering that the pitch went down, in confirmation of their faulty analysis.

Intuitions have priority over internal coherence. The notion that objects of different masses fall at different speed lacks coherence, as Galileo's famous argument established. The notion that a book on a table pushes on the table, but the table does not push back on the book, also does not yield a coherent analysis: There is no physical basis local to the interface between things that permits determining from which direction the force is coming (cf. Clement, 1987). The notion that one can have an average of 1.5 offspring per family may be rejected as nonsensical even though the mathematical meaning of average makes it perfectly coherent (cf. Strauss, 1986). The notion that a computer program "knows" what input values should go into variable names LARGEST dies hard, even though students know in principle that the choice of variable names is theirs, a point incoherent with such wisdom on the part of the computer (cf. Sleeman, 1986). Such examples suggest that people commonly fail to notice the incoherencies in their intuitive mental models, and, often, when incoherencies are brought to their attention, the incoherencies simply do not appear very important. The robust

intuitive model seems worth preserving in the face of a few minor discrepancies.

The grounding of the paradigm's rules is neglected. Multiplication is distributive over addition in algebra, but the square root is not distributive. Air resistance aside, bodies of different masses fall at the same speed. Where do such rules come from? As noted earlier, novices may easily view such rules as "rules of the game," something someone figured out sometime that one just has to learn. However, again as noted earlier, the grounding of rules of algebra essentially lies in rules of arithmetic. Checking a rule of algebra against arithmetic is not merely using a conventional trick, but doing just the right thing -- turning to the epistemological foundation of algebra.

In the case of the hard sciences, it's commonplace to view empirical inquiry as the epistemological foundation. This, of course, makes the foundation inaccessible to most students, who are in no position to go out and do experiments. However, we suggest that in fact a significant part of the foundation of, for example, physics lies in logical coherence and in coherence with gross features of the world, rather than in agreement with the fine structure of the world. For instance, Galileo's argument that objects of any mass fall at the same speed depends basically on logic and on our intuition that snipping a string between two objects is not going to make that much of a difference in their rates of fall. The proportionality of F with m in $F=ma$ can be justified in the same way. Inverse square laws can be conceptualized and justified in terms of a flux concept.

To be sure, such justifications await for final verification on empirical evidence, but they can easily precede it and, in many cases at least, the world would be a very strange place if the principles did not hold up. They also frequently have the advantage of providing more compelling understandings of the phenomena concerned than does mere evidence. They show not that something happens empirically to be the case but why it almost has to be the case. Accordingly, the notion that the epistemological foundations of physics and other hard sciences are through and

through empirical, requiring mountains of data, does mischief by depriving students of an important intellectual resource.

The Inquiry Frame

The inquiry frame is the most ambitious and perhaps hardest to develop of the four discussed. The inquiry frame encompasses knowledge and attitudes having to do with (a) challenging elements of a paradigm or the whole paradigm and (b) extending a paradigm beyond its conventional scope. Such patterns of thought not so commonly found even in experts in a field. On the contrary, one often encounters patterns like these:

Confirmation bias. The tendency to confirm preconceptions emerges strong and clear in work on naive physics. One would hope that sophistication in math, programming, and the sciences would bring with it a general caution about preconceptions. And perhaps that happens to a degree. However, it is not rare to see experts exhibiting problems of confirmation bias not unlike those that plague novices, but on a more sophisticated plane. For an example from the history of physics, Wiser and Carey (1983) discuss how scientists exploring an early model of temperature with admirable methodology persistently overlooked puzzles the data posed for their theory. For a contemporary example, most individuals with considerable training in physics conclude that the pressure at the bottom of a milk bottle is constant regardless of whether the cream is distributed or has separated out at the top. In fact, the pressure changes, but a robust elementary physics schema that says roughly that pressure distributes itself in all directions overrides other reasoning (Jack Lochhead, personal communication).

No problem finding. Even elementary mathematics, science, and programming provide enough information for students to engage in problem finding activities, where they formulate or participate in formulating the problems to be addressed (re mathematics, see Brown & Walter, 1983; Schwartz & Yerushalmy, 1987). However, students show little tendency to engage in problem finding and, indeed, conventional schooling offers few

opportunities for such activity. This is unfortunate, since evidence suggests that a disposition toward problem finding relates strongly to creative productivity (Getzels & Csikszentmihalyi, 1976; Mansfield & Busse, 1981).

Academic applications only. It is very easy for technical knowledge to remain encapsulated in academic contexts, rather than becoming a window on the world in general. For an extreme example, Richard Feynman (1985) writes eloquently of his experience as a visiting professor in a culture with a strong tradition of rote education. Students would memorize definitions of abstract physical concepts and even master textbook problem solving, but have no idea what ordinary events and objects in the world the abstractions described.

Patterns of Misunderstanding

A discussion of the frames of knowledge described above is a useful way to orient oneself to dimensions of variation in the types of misconceptions students frequently display. Beyond this, a closer examination of misconceptions reveals certain "patterns" of misunderstanding that reflect distinctive gaps in the four frames. In this section, we describe three of the most important to illustrate the general idea: naive, ritual, and Gordian patterns of misunderstandings.

It is our view that articulating such patterns serves two major purposes. First, the patterns act as an explanatory tool, enabling one to discuss complex misunderstandings in terms of characteristic profiles across the four frames of knowledge. Second, there is a pedagogical payoff: The patterns suggest directions for effective instructional intervention.

Naive concepts

One of the most typical patterns apparent in many domains might best be called a naive pattern of misconception. This syndrome characterizes the thinking of many novice students. Such students are typically relatively uninformed; the misconception emerges prior to much formal instruction on the topic in question.

Consider an example mentioned before, for instance: Students often take the position that, although a book on a table pushes down on the table, the table does not push up on the book. The students perceive no room for a reaction force, because, based on their experience with the real world, the table is "rigid." When the suggestion is raised that the table might be springy after all, students commonly think otherwise. If it is argued on logical grounds that the notion of one-sided forces makes no sense, students may not see the argument or take the view that it is too finicky (cf. Clement, 1987).

With this example at hand, how can one characterize the naive pattern? With respect to the content frame, students simply lack a concept or a priority among concepts that they might obtain with further instruction. Thus, in the example of the book and the table, one sees the novice treating "rigidity" as a concept with priority over "springiness," (cf. diSessa, 1983). In contrast, the expert recognizes springiness as a much more powerful explanatory tool.

In part, then, the novice's problem is simply one of editing initial conceptions in light of new knowledge as it comes along. However, this in itself does not explain why naive notions often are so robust, another characteristic of the naive pattern. Of course, cognitive load and related developmental factors are likely to be responsible in part (cf. Brainerd, 1983; Case, 1984, 1985). However, it's also helpful to consider the role of the epistemic and inquiry frames in a naive concept. Counter-arguments fall on deaf ears in part because the students have not yet recognized that in science the rules of the game demand that things hang together in an extraordinarily coherent fashion. Small anomalies simply will not do.

Moreover, if one can account for a wide range of phenomena with springiness, and treat rigidity as a kind of limiting case, this parsimony is good scientific coin and the intuitive reality of rigidity simply will have to give way. All this is part of what might be called the "culture of science," a culture which cannot be taken for granted and which students typically have

had little chance to assimilate. As to the inquiry frame, naive students -- like many advanced students and even professional scientists -- show little inclination to examine critically their notions, but rather take intuitions for granted, exhibiting a strong confirmation bias.

We have not yet mentioned the problem-solving frame. This frame is not a central element in the naive pattern, simply because the student is not yet at the level of seriously engaging in technical textbook problem solving. However, as will be emphasized in the next pattern, naive intuitions can continue to affect performance even in students with considerable technical problem-solving skills. In sum, a naive concept points to a shortfall across all frames of knowledge. Poor performance is the consequence of misconceptions in the content frame protected from revision by epistemic and inquiry frames that lack "the culture of science."

Ritual concepts

In contrast to a naive pattern of misunderstanding, what we call the "ritual pattern" arises in students who have undergone considerable formal instruction and may well have developed a high degree of technical problem-solving skill in dealing with textbook problems. At first glance the student seems to have quite a respectable understanding. Yet, further analysis establishes that in fact the student applies knowledge in a somewhat ritualistic fashion, and proves unable to deal with novel situations even when the knowledge base should be more than adequate to the task.

The ritual knowledge syndrome has three notable features. First, the student is typically adept at equation cranking as a means of solving technical problems, exhibiting a clear grasp of many of the intricacies of the notational systems in question; however, the student displays little sensitivity to the "deep structure" of problems in the domain (cf. Chi, Glaser, & Rees, 1982; Chi, Feltovich, & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980; Schoenfeld & Herrmann, 1982). Second, when tasks

are posed that do not suit the equation-cranking approach, unrevised and incorrect intuitive knowledge commonly overrides the student's technical knowledge. For example, many students who have received significant physics instruction, even at the college level, display misconceptions when qualitative problems are posed (Clement, 1982, 1983; McCloskey, 1983).

For instance, students marking the forces at work as a tossed ball rises, peaks, and falls commonly identify a false "impetus" force that sustains the upward rise, matches gravity at the peak, and disappears or at least becomes less than gravity on the fall. This is an interesting misconception in that many of the students displaying the misconception have studied Newton's laws of motion and ostensibly could apply the laws to reason out the problem. Moreover, students could in fact take the given problem and cast it algebraically, finding no force at play other than gravity in analogy to other problems they have done -- for instance, finding how high the ball would rise given a certain upward momentum from the toss. Yet, instead, students resort to a reliance on naive intuitions and ignore the scientific knowledge at their disposal.

A third feature of the ritual pattern of misunderstanding addresses the flip side of the situation described above: Instead of unsound intuitions overriding technical knowledge, overgeneralized technical knowledge dominates a situation. Consider for example the milk bottle example mentioned earlier, in which even professional physicists usually argue that the pressure at the bottom of a milk bottle is no different with the cream dispersed than with the cream separated out at the top. Here, a sophisticated schema about pressure proves overgeneralized and prompts an incorrect response (Jack Lochhead, personal communication).

How do the four frames of knowledge inform us in the case of the ritual pattern? In the content frame, one finds a much more sophisticated verbal knowledge base than in the naive pattern. However, the intuitive imagistic level of students' content understanding has hardly been touched. Naive conceptions persist underneath and resurface when the student does not

immediately see a quantitative solution to a problem. Also, students may have acquired overgeneralized technical schemas that generate errors. In the problem-solving domain, contrary to the naive pattern of behavior, students may in fact exhibit quite sophisticated performance in technical problem solving. However, knowledge in the epistemic and inquiry frames may be hardly more developed than before; students do not display much sense of the epistemic roots of principles nor take a critical stance toward their intuitions.

Gordian concepts

Finally, let us examine what we will call a "Gordian pattern" of misconceptions, so named for the proverbial Gordian knot. The Gordian pattern occurs when experts elaborate a theory with serious undetected errors. In this case the four frames seem to be quite well developed and there is an expectation that the resultant theories are well grounded. Yet, for all that, grossly erroneous conclusions are drawn from data. Consider, for example, the work of 17th century experimenters in the area of thermal phenomena (Wiser & Carey, 1983). This group of scientists had developed a theory of thermodynamics based on a mechanical model. In their Source-Recipient model there was no differentiation between heat and temperature; rather, heat and cold were conceived of having intrinsic force or strength, and were seen as two separate concepts. This led them to concentrate empirical research on seeking out the mechanical effects of heat and cold, adopting a causal explanatory stance of thermal phenomena, and ignoring the possibility of an intervening variable (temperature) to link heat to volume expansion. This led them again and again to miss or reinterpret to suit their theory anomalies in their data.

In this Gordian pattern, the four frames play out in an interesting way. The content frame was constructed from a set of principles and notational system accepted by the scientific community at large. The problem-solving techniques were advanced. In general, the epistemic frame was well developed also: The

scientists certainly took care to justify their claims with observational data. However, confirmation bias appeared in the inquiry frame, even to the point of misreading the significance of data. To be sure, just what one's posture as a scientist ought to be toward anomalies in data with reference to current theory is a dilemma: Some argue that new theories need to be protected for a while from the rigorous test of conformity with data so that they have time to grow (e.g. Feyerabend, 1975). However, at least it seems desirable to know that the anomalies are there, even if one defers considering them.

Teaching for Understanding

The foregoing analyses argue that learning with understanding calls for attention not just to the content frame but to all four frames. Moreover, at different levels of learning the technicalities of a domain, different patterns of misunderstanding present themselves. In this context, two questions arise: To what extent does normal educational practice address the four frames and the patterns of misunderstanding? Is it feasible to design instruction developing abilities associated with the four frames and addressing the patterns?

As to the first of these questions, conventional instruction does not score very well. In the typical school setting, the inquiry frame gets virtually no attention at all. On the contrary, paradigms are taught as received knowledge not subject to challenge. Moreover, the curriculum is dominated by stereotypical "school problems" — school algebra, school physics, school programming, and so on — with students little encouraged to map the content into applications beyond school problems. The epistemic frame fares only a little better. To be sure, in some kinds of mathematics instruction — Euclidean Geometry for example — attention is paid to the question of proof. Also, in some science instruction, key experiments are celebrated and, when accessible, reproduced in the school laboratory. However, all this typically has the character of a ritual exercise where rote learning dominates.

The problem-solving and content frames are the focus of most classroom instruction. On the positive side, certainly students receive exposure to plenty of content and get extensive practice in solving problems. Better students may become quite good at solving textbook problems. However, on the negative side, conventional education offers little direct instruction in heuristics and problem-solving management, adopting an almost pure demonstration and practice approach without attention to the metacognitive side of problem solving. As to the content frame, it is routinely recognized that most curricula attempt to cover far too much content at the cost of depth of understanding.

In summary, conventional education gives most attention to the content frame, next most to the problem-solving frame, next the epistemic frame, and finally and hardly at all to the inquiry frame. But even the content frame does not fare all that well. Moreover, the thrust of our argument has been that teaching for understanding requires attention to all the frames; one cannot just teach content and expect understanding.

Then what about the prospects for education that develops abilities in the various frames? Is this ivory tower idealism, or is there reason to think that such instruction is possible? We urge that instruction of this sort not only is possible but has been carried out a number of times, albeit most often in experimental settings.

The content frame. Here it is natural to consider instructional efforts targeted on specific content objectives. So, for example, White and Horwitz (1987) have constructed and demonstrated the efficacy of a microworld designed to give students a better grasp of Newtonian motion. Sidney Strauss and his colleagues have used instruction by way of analogies to help students to understand the nature of the mathematical mean (Strauss, 1986). We and colleagues at The Educational Technology Center have constructed a "metacourse" for elementary programming instruction that, interleaved with a teacher's normal instruction, provides mental models and strategies that help students to grasp how the computer works and have a strong impact on students'

programming performance (Perkins, Schwartz, & Simmons, in press; Perkins, Farady, Simmons, & Villa, 1986). There are many other examples of like approaches, of course, including additional research undertaken at ETC in the area of mathematics (e.g., Kaput, 1986; Kaput, Luke, Poholsky, & Sayer, 1986; Schwartz & Yerushalmy, 1987) and science, specifically, weight and density (e.g., Frenette, 1987; Smith, Snir, Grosslight & Frenette, 1986) and heat and temperature (e.g., Wiser, 1985).

The problem-solving frame. While the foregoing examples involve and inform problem solving, they do not focus on the problem-solving process extensively. In contrast, the work of Alan Schoenfeld has emphasized the direct teaching of heuristics and problem management strategies for mathematical problem solving (Schoenfeld, 1980, 1982, 1985; Schoenfeld & Herrmann, 1982). In experiments with a college-level intensive course, Schoenfeld has demonstrated striking improvements in students' mathematical problem-solving abilities, with transfer to problems of unfamiliar types and with changes in students' classification of problems in the direction of expert mathematical problem solvers (Schoenfeld, 1982; Schoenfeld & Herrmann, 1982).

The epistemic frame. While one can approach development of students' understanding in various ways, a classic approach in the Piagetian tradition is to involve students in situations that create an epistemic tension between their initial conceptions and the situations examined, luring them into an inquiry process that leads them to restructure their conceptions. To mention an example already discussed, students of high school physics initially tend to hold that although a book on a table pushes down on the table, the table does not push up on the book -- there is no reaction force, because the table is rigid and cannot push back.

John Clement and his colleagues have explored a Socratic classroom procedure in which the teacher moderates a discussion exploring the logic of this position: What about a book sitting on a spring? What about a bendy table? At the opposite extreme, what about a fly standing on a road? Through this activity,

many students come to see that coherence is better served by the position that everything bends a little and there is always a reaction force; otherwise arbitrary boundaries must be drawn (Clement, 1987). In a related effort, these investigators have developed a piece of software that creates a similar epistemic tension by constantly asking users to classify cases that fall between cases they have classified as having and not having reaction forces; substantial impact on students' beliefs has been demonstrated (Jack Lochhead and John Clement, personal communication).

The inquiry frame. The "Geometric Supposer" is a piece of software developed by Schwartz and Yerushalmy (1987), designed to restore an inquiry process to instruction in Euclidean Geometry. The Geometric Supposer makes geometric constructions easy by providing computer assistance in dropping altitudes and angle bisectors, adding parallels, and so on. It also permits automatically "replaying" a construction with different starting points -- a new triangle for instance -- to allow examining multiple cases for similarities. In geometry classrooms, the Geometric Supposer provides a tool with which students explore possible geometric relations, devise conjectures, test their conjectures informally with the Geometric Supposer, and then often attempt formal proofs. Students routinely rediscover standard theorems rather than learning them out of the text and, from time to time, students have formulated unknown theorems.

Another important resource for inquiry-oriented instruction in mathematics is The Art of Problem Posing, by Brown and Walter (1983). The authors argue that, while finding problems plays hardly any role in typical instruction, it is essential to the mathematical enterprise; they offer numerous examples to show how problem posing can be made a part of mathematics instruction. For a third example, Lampert (1986) discusses how elementary school students approaching the mysteries of arithmetic can engage in serious explorations of the way numbers work.

The fact that efforts such as these can be cited demonstrates that in science, math, and computer education there already

exists an awareness of the problems of understanding and instruction surveyed via the four frames. In that context, we suggest that the four frames and other efforts in a similarly integrative spirit can inform the field in at least the following ways; they can help to:

- o Identify the range of explanations for misunderstandings and the range of potential instructional tactics by mapping more clearly different aspects of understanding, as the four frames attempt to do.
- o Press for the role of general knowledge about problem solving, epistemics, and inquiry that informs understanding particular concepts.
- o Guide in organizing instructional efforts of greater scope than those reviewed, that attempt to choreograph attention to different sides of understanding within and across the subject matters of science, math, and programming.

Certainly the three needs outlined are not likely to be met by any one scheme. Nonetheless, models in this direction seem necessary to revitalize educational practice, especially because educational practice, like the fields examined here, also is subject to reductive misconceptions. Broadly speaking, education tends to be dominated by default assumptions about what knowledge and understanding are and how they are acquired. The default position for many science students is that force varies with velocity, not acceleration. Likewise, the default assumption for many involved in the educational enterprise -- students, teachers, and curriculum writers alike -- is that understanding varies with information and practice.

Of course, sometimes these default assumptions are correct. At terminal velocities in a resistive medium, force varies entirely with velocity. Where there are no particular conceptual barriers, understanding is pretty much a matter of information

and practice. Unfortunately, both theories miss the essence. Consequently, educating for understanding means not only helping students to remake their concepts of force, fractions, or FOR-NEXT loops but helping the educational community at large to remake reductive concepts of learning and understanding by means of more encompassing, compelling, and accessible theories of instruction.

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References

- Anderson, J. R. (1983). The architecture of cognition. Cambridge, Massachusetts: Harvard University Press.
- Anzai, Y., & Yokoyama, T. (1984). Internal models in physics problem solving. Cognition and Instruction, 1, (4), 397-450.
- Brainerd, C. J. (1983). Working-memory systems and cognitive development. In C. J. Brainerd, (Ed.), Recent advances in cognitive-developmental theory: Progress in cognitive development research (pp. 167-236). New York: Springer-Verlag.
- Bransford, J. D., Franks, J. J., Vye, M. J., & Sherwood, R. D. (1986, June). New approaches to instruction: Because wisdom can't be told. Paper presented at the Conference on Similarity and Analogy, University of Illinois.
- Brown, J. S., & VanLehn, K. (1980). Repair theory: A generative theory of bugs in procedural skills. Cognitive Science, 4, 379-426.
- Brown, S. I., & Walter, M. I. (1983). The art of problem posing. Hillsdale, New Jersey: Lawrence Erlbaum Associates.
- Case, R. (1984). The process of stage transition: A neo-Piagetian viewpoint. In R. J. Sternberg (Ed.), Mechanisms of cognitive development (pp. 19-44). New York: W. H. Freeman and Company.
- Case, R. (1985). Intellectual development: Birth to adulthood. New York: Academic Press.
- Chase, W. C., & Simon, H. A. (1973). Perception in chess. Cognitive Psychology, 4, 55-81.
- Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. Sternberg (Ed.), Advances in the psychology of human intelligence (pp. 7-75). Hillsdale, New Jersey: Erlbaum.
- Chi, M., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.
- Clement, J. (1982). Students' preconceptions in introductory mechanics. American Journal of Physics, 50, 66-71.
- Clement, J. (1983). A conceptual model discussed by Galileo and used intuitively by physics students. In D. Gentner & A. L. Stevens (Eds.), Mental models. Hillsdale, New Jersey: Erlbaum.
- Clement, J. (1987, April). The use of analogies and anchoring intuitions to remediate misconceptions in mechanics. Paper presented at the annual meeting of the American Educational Research Association, Washington, D.C.
- diSessa, A. (1983). Phenomenology and the evolution of intuition. In D. Gentner & A. L. Stevens (eds.), Mental models (pp. 267-298). Hillsdale, New Jersey: Lawrence Erlbaum Associates.
- Feyerabend, P. (1975). Against method: Outline of an anarchistic theory of knowledge. London: New Left Books.
- Feynman, R. (1985). Surely you're joking, Mr. Feynman: Adventures of a curious character. New York: W. W. Norton.
- Frenette, M. (1987). The role of representational features in children's learning from a computer model: A pilot study (ETC Report No. TR86-13). Cambridge, Massachusetts: Educational Technology Center, Harvard Graduate School of Education.
- Getzels, J., & Csikszentmihalyi, M. (1976). The creative vision: A longitudinal study of problem finding in art. New York: John Wiley & Sons.
- Glaser, R. (1984). Education and thinking: The role of knowledge. American Psychologist, 39, 93-104.
- Kaput, J. (1986). Information technology and mathematics: Opening new representational windows (ETC Report No. 86-3). Cambridge, Massachusetts: Educational Technology Center, Harvard Graduate School of Education.
- Kaput, J., Luke, C., Poholsky, J., & Sayer, A. (1986). The role of representations in reasoning with intensive quantities: Preliminary analyses (ETC Report No. TR86-9). Cambridge, Massachusetts: Educational Technology Center, Harvard Graduate School of Education.
- Kuhn, T. (1962). The structure of scientific revolutions. Chicago: University of Chicago Press.
- Lampert, M. (1986). Knowing, doing, and teaching multiplication. Cognition and Instruction, 3(4), 305-342.
- Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Modes of competence in solving physics problems. Cognitive Science, 4, 317-345.
- Mansfield, R. S., & Busse, T. V. (1981). The psychology of creativity and discovery. Chicago: Nelson-Hall.
- McCloskey, M. (1983). Naive theories of motion. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 299-324). Hillsdale, New Jersey: Lawrence Erlbaum Associates.
- Newell, A., & Simon, H. (1972). Human problem solving. Englewood Cliffs, New Jersey: Prentice-Hall.
- Pea, R. D. (1986). Language-independent conceptual "bugs" in novice programming. Journal of Educational Computing Research, 2 (1), 25-36.
- Perkins, D. W., Farady, M., Simmons, R., & Villa, E. (1986). A "meta-course" to enhance the teaching of BASIC (ETC Report No. TR86-12). Cambridge, Massachusetts: Educational Technology Center, Harvard Graduate School of Education.
- Perkins, D. W., Hancock, C., Hobbs, R., Martin, F., & Simmons, R. (1986). Conditions of learning in novice programmers. Journal of Educational Computing Research, 2(1), 37-56.
- Perkins, D. W., & Martin, F. (1986). Fragile knowledge and neglected strategies in novice programmers. In E. Soloway & S. Iyengar (Eds.), Empirical studies of programmers (pp. 213-229). Norwood, New Jersey: Ablex.
- Perkins, D. W., Martin, F., & Farady, M. (1986). Loci of difficulty in learning to program (ETC Report No. 86-6). Cambridge, Massachusetts: Educational Technology Center, Harvard Graduate School of Education.
- Perkins, D., Schwartz, S., & Simmons, R. (in press). Instructional strategies for the problems of novice programmers. In Mayer, R. (Ed.), Teaching and learning computer programming: Multiple research perspectives. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

- Polya, G. (1954). Mathematics and plausible reasoning (2 vols.). Princeton, New Jersey: Princeton University Press.
- Ranney, M. (1987, April). Restructuring conceptions of motion in Physics-naïve students. Presented at the annual meeting of the American Educational Research Association, Washington, D.C.
- Roth, C., Chaiklin, S. (1987, April). Emerging consensus in novice physics problem-solving research. Paper presented at the annual meeting of the American Educational Research Association, Washington, D. C.
- Schoenfeld, A. H. (1980). Teaching problem-solving skills. American Mathematical Monthly, 87, 794-805.
- Schoenfeld, A. H. (1982). Measures of problem-solving performance and of problem-solving instruction. Journal for Research in Mathematics Education, 13(1), 31-49.
- Schoenfeld, A. H. (1985). Mathematical problem solving. New York: Academic Press.
- Schoenfeld, A. H. & Herrmann, D. J. (1982). Problem perception and knowledge structure in expert and novice mathematical problem solvers. Journal of Experimental Psychology: Learning, Memory, and Cognition, 8, 484-494.
- Schwartz, J. L., & Yerushalmy, M. (1987). The geometric supposer: Using microcomputers to restore invention to the learning of mathematics. In D. N. Perkins, J. Lochhead, & J. Bishop (Eds.), Thinking: Proceedings of the second international conference. Hillsdale, New Jersey: Lawrence Erlbaum Associates.
- Sleeman, D., Putnam, R., Baxter, J., & Kuspa, L. (1986). Pascal and high school students: A study of errors. Journal of Educational Computing Research, 2 (1), 5-23.
- Smith, C., Snir, J., Grosslight, L., & Frenette, M. (1986). Promoting 6th graders' understanding of density: A computer modeling approach (ETC Report No. 1R86-5). Cambridge, Massachusetts: Educational Technology Center, Harvard Graduate School of Education.
- Strauss, S. (1986). Three sources of differences between educational and developmental psychology: resolution through educational-developmental psychology. Instructional Science, 15, 275-286.
- VanLehn, K. (1981a). Bugs are not enough: Empirical studies of bugs, impasses and repairs in procedural skills. Palo Alto, California: Cognitive and Instructional Sciences Group, Palo Alto Research Center, Xerox.
- White, B. and Horwitz, P. (1987). ThinkerTools: Enabling children to understand physical laws (BBN Inc. Report No. 6470). Cambridge, Massachusetts: BBN Laboratories Inc.
- Wiser, M. (1985). Designing a micro-computer based laboratory to induce the differentiation between heat and temperature in ninth graders (ETC Report No. 85-17). Cambridge, Massachusetts, Harvard Graduate School of Education.
- Wiser, M., & Carey, S. (1983). When heat and temperature were one. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 267-298). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

SECONDARY SCHOOL STUDENTS' LEARNING DIFFICULTIES IN STOICHIOMETRY

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1. Introduction

In this lecture I want to deal with the difficulties experienced by secondary school students and undergraduates studying chemistry when attempting stoichiometric calculations. A large sample of students was asked to work through specific multiple choice questions. We were particularly interested to find out how the students obtained the answer.

Our hypothesis is as follows: when students make errors, they follow a certain strategy to reach a given result. These strategies may be investigated by the use of empirically designed multiple choice questions, in case students choose particular distractors. By studying the answer profile of a given multiple choice question, and using notes made by students while they were answering the question, it is possible to throw some light on these strategies. In order to highlight possible strategies, I will illustrate my talk with a number of multiple choice questions and the analysis of the answers given.

2. The Concept of percentage of mass of an element in a compound

2.1 Meaning of the answer profile of a multiple choice question

In a small study of 549 secondary school students, every third student was asked to tackle question 11.000.

Question 11.000

What is the percentage of hydrogen by mass in the compound C_2H_6 ?

20 % (A) / 25 % (B) / 33 % (C) / 75 % (D)

The students came from all parts of the Federal Republic of Germany. Their ages ranged from 16 to 19 years and they came from the 11th to 13th grade, i. e. from the last three years of the Gymnasium. They had either studied a basic course of 2 hours per week chemistry or a more advanced course of 5 hours per week.

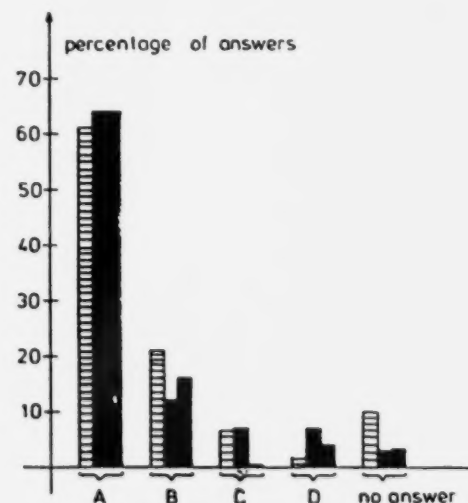


Figure 1: The answer profile for question 11.000. The question was given to the 11th grade (striped column) and in basic and advanced courses of the 12th and 13th grades (both columns black). The figure shows the percentage of students choosing particular options and those not answering the question.

Figure 1 shows the answer profile for question 11.000. The y-axis shows the percentage of students choosing each option as well as the percentage not answering the question. The x-axis shows the pattern of response to each of the options by three groups of pupils; the striped column gives the results for grade 11, the second (black) column refers to grades 12 and 13 that have followed the basic course and the third column (also black) applies to students in grades 12 and 13 that have followed the advanced course.

As may be seen from figure 1, more than 60 % of students in all three groups obtained the correct answer. The most popular distractor was B.

By studying the notes made by students, it is possible to determine how students arrived at the answer in distractor B. They do not calculate the percentage of mass MA:

$$\begin{aligned} (1) \quad MA &= \frac{6 M(H)}{6 M(H) + 2 M(C)} \cdot 100 \% \\ &= \frac{m(H)}{m(H) + m(C)} \cdot 100 \% \end{aligned}$$

but the simple mass ratio MV:

$$(2) \quad MV = \frac{6 M(H)}{2 M(C)} \cdot 100 \% = \frac{m(H)}{m(C)} \cdot 100 \%$$

In the equations (1) and (2) above $M(H)$ is the molar mass of hydrogen and $M(C)$ is the molar mass of carbon. $m(H)$ is the mass of hydrogen and $m(C)$ is the mass of carbon in one mole of ethane. The reasoning used by a typical student choosing the distractor B is:

"Divide 24 by 6, this gives 4, $1/4$ of 100 % is 25 %."

It is also possible to deduce from the students' records of their attempts that a number of them decided to choose distractor D because they did not differentiate between the percentage of mass MA and percentage of atoms AA:

$$\begin{aligned} (3) \quad AA &= \frac{n(H)}{n(C) + n(H)} \cdot 100 \% \\ &= \frac{m(H)}{m(C) + m(H)} \cdot 100 \% \end{aligned}$$

A typical student would argue: " C_2H_6 , the proportion of mass of hydrogen $6/8 = 3/4 = 75 \%$ ". I shall return to this particular mistake later in my lecture.

The analysis of test results has enabled us to derive two hypotheses. According to the answer profile to question 11.000, only one incorrect method of calculation the answer might have been suspected. With such a small sample of pupils this may not be too surprising. It should also be remembered that the sample was made up of roughly equal proportions of students from grade 11 as well as those that had followed basic courses or advanced courses in chemistry. Those that had followed the advanced course do not make as many mistakes but are strongly represented. This presumably led to the situation where the second important distractor did not show up in the answer profile.

2.2 The general nature of the results

I would now like to add an additional dimension to the issue. The students who took part in the research did not get there by chance and in no sense can they be regarded as a representative sample of all pupils in the statistical sense. It would therefore be wrong to generalise the results and hypotheses that have been obtained. If one wants to discover whether the hypotheses are valid for other samples, then the same research must be repeated with these other samples. We therefore obtained multiple choice questions, with answer profiles, from a number of examinations boards in other countries in order to check (1) whether the multiple choice questions contain the

type of distractor which we would expect according to our hypotheses to be chosen by students and (2) whether the students actually choose these distractors.

It is of course possible in a study of this kind to use multiple choice questions that have been previously set and to check whether the same answer profile is obtained as in Germany. With question 11.000 we did precisely this. In the Dutch language the text sounds as follows:

Hoe groot is het massapercentage waterstof in de verbinding C_2H_6 ?
20 % (A) / 25 % (B) / 33 % (C) / 75 % (D)

The Central Instituut voor Toetsontwikkeling in Arnhem provided us with the results of the above test in the MAVO exam in 1981. 1067 candidates took part in this test. The percentage choosing particular answers was as follows:

(A) 53 % / (B) 16 % / (C) 12 % / (D) 19 %

As may be seen from this sample, the most common distractors are indeed (B) and (D). Our hypotheses appear to hold for this test given in the Netherlands.

We obtained another test from the Examinations Committee of the American Chemical Society:

Which is the percent by mass of carbon in oxalic acid, $H_2C_2O_4$?
2.22 % (1) / 3.75 % (2) / 25.0 % (3) / 26.7 % (4) / 71.1 % (5)

The correct answer is (4) and the more important distractors are (2) and (3).

If the students calculate the mass ratio (without taking hydrogen into account) then they obtain the value 37.5 % as follows:

$$(4) \quad MV = \frac{2 M(C)}{4 M(O)} \cdot 100 \% = \frac{m(C)}{m(O)} \cdot 100 \% \\ = 37.5 \%$$

The questions set by the American Chemical Society does actually contain an answer containing these figures but the decimal point has been moved one place to the left. It could be that the students are convinced that their calculation is correct and regard the 3.75 % as a typographical error and are satisfied with their answer.

If the percentage of atoms AA of carbon is calculated, instead of the percentage of mass, one gets to distractor (3):

$$(5) \quad AA = \frac{n(C)}{n(H) + n(C) + n(O)} \cdot 100 \% = \frac{2}{8} \cdot 100 \% \\ = 25 \%$$

I would now like to consider a third question set abroad which deals with the concept of percentage of mass but set in a somewhat different way as follows:

Which one of the compounds represented by the following formulae has the highest proportion of hydrogen by mass in 1 mol (1 g formula)?

H_2O (A) / NH_3 (B) / PH_3 (C) / SiH_4 (D) / SnH_4 (E)

The following table shows the results for each chemical compound depending on the basic concepts being applied:

	percentage of mass	mass-ratio	percentage of atoms
H ₂ O	11 %	13 %	67 %
NH ₃	*18 %	*21 %	75 %
PH ₃	9 %	10 %	75 %
SiH ₄	13 %	14 %	*80 %
SnH ₄	3 %	3 %	*80 %

A little thought shows that the mass-ratio must be large if the percentage of mass is large. In this question the student can make a wrong calculation and yet reach the correct result. In the table the highest values are indicated by a star.

If the students calculate the percentage of atoms, then they will wonder why two answers are the same and they will probably start on a different strategy to solve the problem.

This question is therefore not a good question and the setter should have realised this. When multiple choice tests are being developed by Examination boards a number of experts are involved. The tests are always pre-tested before they are set in a proper examination. Someone working on their own in the construction of multiple choice tests does not have these facilities and it is therefore not surprising that tests used by Examination Boards are better than those constructed by test-book authors.

2.3 Possible origins for the misconceptions

How is it that some students define the concept of percentage of mass differently from chemists? Our students have learned their chemistry in school and from books. It is not possible for us to control what happens in lessons but we can look at textbooks that are used by most students.

We have looked carefully at five of the most popular chemistry books that are used in the Federal Republic of Germany to ascertain how the concept of percentage of mass is handled. Frequently instead of percentage of mass the expression mass percentage, weight percentage, percent combination, percentage number or simply percentage are used. It is of course possible to deduce the meaning of percentage of mass from worked examples given in the chemistry textbooks but the concept is not defined as clearly as it should be. The casual reader may not even notice that it is necessary to distinguish between mass-ratio and percentage of mass. Pupils that have not understood the concept of percentage of mass, seem to make up their own definitions which are often wrong.

It could be that the teachers regard the simple concept of percentage of mass as so trivial that they do not bother to explain this clearly to the students. Only those students who think clearly about this work are likely to realise that there is a difference and they will have been successful with our question 11.000.

3. Relationship between mass and number of particles

3.1 Students' understanding of chemical symbols

I would now like to show you two further questions (number 16.341 and 91.000) which we have used in a larger study. The sample consisted of 6,262 students from grades 12 to 13 and in the case of question 91.000, we had an additional 650 first-year under-graduates from six different universities within the Federal Republic. Every eighth pupil and every third university student was given one of the following questions i. e. the results are based on a sample of 800 school pupils and 200 university students.

Let us first of all look at question 16.341 and the answer profile (Figure 2):

Question 16.341

The formula for sulphur dioxide is SO_2 . How many grammes of sulphur are contained in 6 grammes of sulphur dioxide?

4 g (A) / 3 g (B) / 2.5 g (C) / 2 g (D)

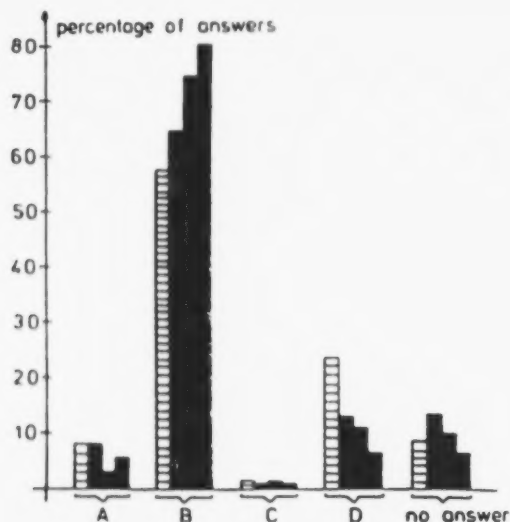


Figure 2: Answer profile for question 16.341. This question was given to students in grade 10 (striped column) and also to pupils in grade 11 (black column) and also to pupils in grades 12 and 13 who had followed the basic and more advanced chemistry courses (two black columns).

The most important distractor is D, and A must also be taken into account. An analysis of the pupil records shows what thoughts led to their obtaining these results:

" SO_2 contains 3 atoms, one of which is sulphur. So sulphur must be $1/3$ of the weight: 2 g."

Here it is assumed - deliberately or not - that the ratio of masses is directly proportional to the ration of atoms:

$$(6) \quad n(\text{S}) : n(\text{O}) = m(\text{S}) : m(\text{O})$$

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This mistake has already occurred in the percentage of mass question (see (3)). It leads in question 16.341 to distractor D.

Other pupil records point to the fact, that the ratio of molar masses is often equated with the ratio of masses:

$$\text{"... } 32/16 = 2, \text{ ratio S : O} = 2 : 1, 6/3 = 2.2 = 4 \text{ (S), } 6/3 = 2.1 = 2 \text{ (O)"}$$

In this case the pupil has divided the 6 g of sulphur dioxide into three parts and allocated $2/3$ to sulphur and $1/3$ to oxygen. This is based on the wrong assumption:

$$(7) \quad M(\text{S}) : M(\text{O}) = m(\text{S}) : m(\text{O})$$

This explains why distractor A was chosen.

In question 91.000 the chemical formula is not given but has to be deduced.

Question 91.000

2 g of a compound contains 1 g copper, the rest is sulphur. Which of the following formulae satisfies this condition?

CuS (A) / CuS_2 (B) / Cu_2S (C) / Cu_2S_2 (D)

Here also two distractors are in particular evidence (Figure 3):

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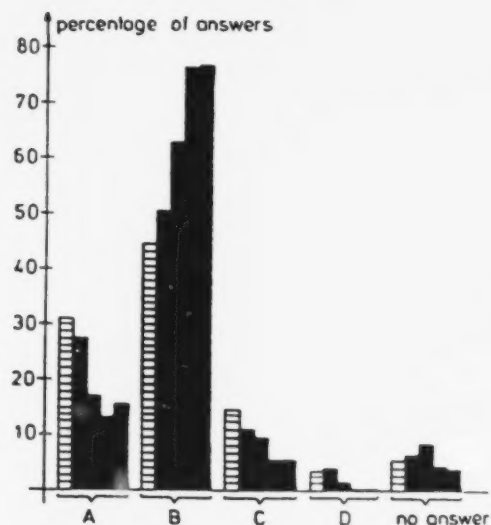


Figure 3: Answer profile for question 91.000. The striped column refers to pupils from grade 10, the first black column to students from grade 11, the next two black columns refer to pupils in grades 12 and 13 having followed the basic and more advanced chemistry courses respectively and the final column refers to students following the chemistry diploma and chemical technology courses at university.

The same mistake is made here as in the SO_2 question 16.341. Pupils do not distinguish between the ratio of atoms and the ratio of masses:

$$(8) \quad m(\text{Cu}) : m(\text{S}) = n(\text{Cu}) : n(\text{S})$$

Here is an example of a commentary provided by one chemistry student in the first semester:

"As the proportion of Cu to S is 1 : 1, this must show itself in the chemical formula . . . hence solution A."

Again it is evident that the ratio of molar masses is regarded as the same as the ratio of number of atoms:

$$(9) \quad M(\text{Cu}) : M(\text{S}) = n(\text{Cu}) : n(\text{S})$$

Here is a typical student commentary:

"Cu has 64 g, S has 32 g, so the proportion is 2 : 1, so Cu_2S ."

3.2 The generalisability of the results

It seems likely that hypotheses (6) to (9) are generally applicable as we have used them to explain how particular distractors were chosen by students both in Germany and in other countries. For example:

The formula of an oxide of sulphur is SO_2 . What mass of oxygen combines with 16 grams of sulphur in this oxide? (Relative atomic mass: O 16, S 32)

2 g (A) / 4 g (B) / 8 g (C) / 16 g (D) / 32 g (E)

This question was first set in England and is our question number 16.341. It was sent to us by the Oxford and Cambridge Schools Examination Board. The question was set in an Ordinary level examination in 1983 and was attempted by 4,641 pupils. The percentage of pupils choosing each option was as follows:

(A) 1 % / (B) 4 % / (C) 15 % / (D) 66 % / (E) 13 %

The most important distractors are C and E. These are selected either if the candidate compares molar masses:

$$(10) \quad M(\text{S}) : M(\text{O}) = 32 : 16 = 16 : 8$$

or compares the number of atoms:

$$(11) \quad n(\text{S}) : n(\text{O}) = 1 : 1 = 16 : 32$$

Question 91.000 is very similar to one set by the Scottish Examination Board:

An analysis of a sulphide of copper gives the following results:

mass of copper = 1.0 g (relative atomic mass 64)

mass of sulphur = 1.0 g (relative atomic mass 32)

Which formula correctly represents this sulphide?

CuS (A) / CuS₂ (B) / Cu₂S (C) / Cu₂S₂ (D)

The above question was set in the Ordinary grade examination in 1983 and the percentage of pupils choosing each option was as follows:

(A) 15 % / (B) 57 % / (C) 27 % / (D) 1 %

the most important distractors were A and C. These are obtained by using the ratio of masses

(12) $m(\text{Cu}) : m(\text{S}) = 1 : 1$

or by considering the ratio of molar masses

(13) $M(\text{Cu}) : M(\text{S}) = 63 : 32 = 2 : 1$

The following question was also obtained from the Scottish Examination Board:

An analysis of an oxide of tellurium (Te) gave the following result:

mass of tellurium = 8 g

mass of oxygen = 1 g

Which of the following formulae correctly represents this oxide? (Take the relative atomic mass of tellurium as 128, oxygen as 16)

TeO (A) / TeO₂ (B) / TeO₃ (C) / TeO₄ (D)

This question was set in the Ordinary grade examination in 1979 and the percentage of candidates choosing each option was as follows:

(A) 76 % / (B) 7 % / (C) 6 % / (D) 11 %

If the strategy of proportion of number of atoms or the proportion of molar masses is used, the formula Te₈O is obtained. This solution is not contained in the question and in any case it would be a somewhat strange formula.

It should be noted that the students had greater success with the Tellurium oxide question than with the Copper oxide question. Although the above two questions were set four years apart, the Scottish Examination Board monitors the performance of pupils and it is possible to say that there was no change in standards in this relatively short time interval. It is also possible to say that the candidates came from the same catchment areas and that chance determined which particular set of questions they were given in the examination.

As part of this study we gave pairs of questions to the same student sample. With one pair it is possible to obtain the same answer if the mass ratio is assumed to be equivalent to the ratio of atoms, but by using another pair, this is not the case. The questions are more difficult if the above mistake is recognised by the candidate. This particular aspect of the research is being reported in the Journal of Research in Science Teaching and I will not elaborate it here.

The above finding is very interesting. One sees, for instance, that two questions that look completely alike nevertheless are different, on the other hand the result leads one to be able to say something about the stability of misconceptions.

First assumption: The pupils keep to the same strategy (wrong or right) in tackling both questions. In the case of the copper sulphide question, their answer is one of the distractors whereas in the tellurium oxide question, there is no appropriate answer and they are unclear what to do. They do not attempt the question again. In this case both questions should be equally

difficult.

Second assumption: Pupils who obtained one of the preferred distractor answers in the copper sulphide question, find no appropriate answer in the case of the tellurium oxide question. They realise that they have used a wrong strategy and try another one. The tellurium oxide question must therefore appear to be easier and this is shown to be so in the analysis.

3.3 Implications of the findings

I will now attempt to interpret the three types of mistakes identified in (6) to (9). Students who obtain the correct answer to questions 16.341 and 91.000 must relate three variables correctly: the mass (m), the molar mass (M) and the number of moles (n). Many pupils simplify their calculations by only considering two variables and forgetting about the third. This is in line with the findings of Piaget, who states that the ability to deal with three variables is a sign of formal operational thinking. Questions 16.341 and 91.000 should therefore divide the sample into formal operational and non-formal operational thinkers. However if question 16.341 is used then it would appear there are more formal operational thinkers than if question 91.000 is considered. It would seem that the criteria "able to use three variables" is not sufficient to explain our empirical findings.

The main mistake pupils make is to put the mass relation of the elements A and B of a chemical compound on a level with the atom ratio according to

$$(14) \quad m(A) : m(B) = n(A) : n(B)$$

Do they really assume, without reference to the particle concept, that chemical formulae reflect the mass ratio of individual elements? In doing so the calculations would be considerably simplified, but one could only handle chemical formulae and equations on the macroscopic scale. Predictions on the basis

of the number of atoms (in the sense of Dalton) would not be possible.

This interpretation is in line with that of the Piagetian school, which states that formal operational thinkers satisfy the criterion that they are able to think with abstract models. Students who used the strategies (7) and (9) make the additional mistake of using the concept of molar mass, which is superfluous if atoms are not considered in the definition of chemical formulae. The molar mass is the mass which these students assume determines chemical reactions.

Because responses to questions 16.341 and 91.000 divide the sample into two different groups of formal operational thinkers, this theory does not explain the findings sufficiently. This has already been mentioned.

Let us now consider the misconceptions of pupils quite formally. If students use (14) they assume - consciously or unconsciously -, that the molar masses $M(A)$ and $M(B)$ are equal:

$$(15) \quad \frac{m(A)}{n(A)} = \frac{m(B)}{n(B)} \Rightarrow M(A) = M(B)$$

They also used (7) and (9), which can be written in general form as

$$(16) \quad M(A) : M(B) = m(A) : m(B)$$

and

$$(17) \quad M(A) : M(B) = n(A) : n(B)$$

If (16) and (17) are combined we get to relationship (14) that is the pupils arrive at the statement $M(A) = M(B)$. By transforming (16) we can recognise in what sense the two cases are different. In addition to (15) the following relationship must hold:

$$(18) \quad \frac{m(A)}{M(A)} = \frac{m(B)}{M(B)} \Rightarrow n(A) = n(B)$$

In this way we are able to place the misconceptions in a hierarchical order.

4. Conclusion

Our research has shown that many pupils, who do not get the correct result, have nevertheless had useful thoughts about chemical combinations, even if these do not coincide with the basic principles used by chemists. Many errors occur because the wrong strategy is used. It might even be postulated that some pupils have obtained the correct result because they have thought less about the chemistry and only applied learnt algorithms. Many errors made by pupils might even be regarded as 'honest' and pupils should not be ashamed of them.

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References

- Schmidt, H.-J., Secondary School Students' Strategies and Errors in Stoichiometry, *Journal of Research in Science Teaching*, to be published
- Schmidt, H.-J., How pupils think - empirical studies on pupils' understanding of simple quantitative relationships in chemistry. *School Science Review*, 1984, 66, 234, 156 - 160

COGNITIVE CONSTRAINTS AND SPONTANEOUS
INTERPRETATIONS IN PHYSICS

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Physics is legendary considered a subject incomprehensible to the student (Halloun & Hestenes, 1985).. What the teacher may hope to achieve from the student is a set of memorized formulas, but only in rare occasions does the student obtain an acceptable understanding on phenomena such as the falling of a stone, the movement of the moon, or the transmission of the heat.

The difficulties for the conceptual understanding in physics has been attributed to the lacking, by the student, of an appropriate level of cognitive development to cope with certain abstract concepts, or simply, without basis for it, to the lack of studying. In the last decade, however, the importance of the student's intuitive or spontaneous ideas has been made evident, this he acquires by himself and not as a result of his studies and interact with the ideas the teacher transmits, making his learning more difficult. These set of ideas, that allows the student comprehend many situations of everyday life, constitute, at times, a frame of knowledge clearly identified which strongly resists being altered (Viennot, 1979, Saltiel & Malgrange 1980, Clough & Driver, 1986).

We have considered more suitable to use the term "spontaneous interpretations" to refer to the explanations given by the student to situations presented in physics, instead of other more frequent denominations such as "misconceptions" or "alternative frameworks", since, on one hand, these do not constitute isolated misconceptions, but on the contrary, they are related to each other and are determined by an inseparable theoretical elaboration (Helm, 1983, Murphy & Medin 1985); and on the other hand, these interpretations can only be considered

simply as alternatives when compared to the accepted science. Nevertheless, its value, from the cognitive view, resides in itself, in constituting bodies of information, not taught, and which are used spontaneously by the student to give meaning to his environment.

If learning science is mediatized by ideas possessed by the student before receiving formal teaching, it should therefore be of great value to consider these ideas in the elaboration of suitable teaching strategies. However, even though a great number of descriptive investigations have been accomplished to analyse these spontaneous ideas, the results in applying the suggestions and implications in teaching have been of little success or of complete failure (Smith & Lott, 1983).

Since the modification of these spontaneous ideas depend on how they are analysed (Viennot, 1985), it is probable that the approaches and analysis that have been made up to the present time, on its origin, development and changes, have not been accurate enough, and it may well be necessary, therefore, to continue seeking other approaches to give the problem a new outlook.

The work is inscribed within the search of new theoretical approaches in order to analyse the results of the investigations made on spontaneous interpretations in physics. In this work we propose the "cognitive constraints" perspective like a valid --- alternative for that analysis. According to this perspective, the cognitive development would be partially guided by a set of constraints, highly stable, that would either facilitate or hinder the learning of certain structures of knowledge. The characteristics of this perspective are also described, analysing the similarities and differences between these cognitive constraints and the ideas of Pines & West (1986) about scientific education, and the ideas on "conceptual change" of Posner, Strike, Hewson, Gertzoq (1982). Some examples of cognitive constraints in physical

interpretations are hereby outlined, even though its value is still recognized as being of a heuristic nature, and that there may be still a long way to go before obtaining the detailed type of constraints that are hindering the learning of physics.

2.- Characteristics of spontaneous interpretations in physics.

A great number of facts have been gathered in order to identify the spontaneous thought of the students in physics, in different areas and using different methodological approaches. The results clearly evidence that the students coincide in -- very high proportions in the interpretation of specific situations. This coincidence in a general pattern of interpretation, which with small variations is shared by almost all students, has been accepted by most investigators (Saltiel & Malgrange, 1980. Erickson, 1980, Mc Closkey, 1983, Whitaker, 1983, Mc Dermott, 1984); even though such general pattern of interpretation could depend on the situation established -- (Clough & Driver 1986)..

The longitudinal studies carried out with students of different educational levels, and consequently of different ages, have revealed the tenacity of those spontaneous interpretation, that are not altered by systematic courses in physics, or by the maturity of the person, outliving the formal teaching which contradicts them. (Viennot, 1979, Gilbert, Watts, & Osborne, 1982, Gowin 1983, Sebasti , 1984),

Some investigators have suggested certain parallelism between spontaneous interpretations and theories historically overcome, such as Aristotelian and medieval theories, conceiving the same phenomena (Clement, 1982, Whitaker, 1983), however, even though there is no doubt that certain parallelism exist between both interpretations, a strict correspondence has been discarded (Mc Clelland 1984, Saltiel & Viennot, 1985, Lythcott, 1985).

In short, two of the most outstanding characteristics

presented in the student's spontaneous interpretations are: (a) there is a common pattern of spontaneous interpretations widely spread and (b) the patterns of spontaneous interpretations are strongly resistant to change. Consequently, all intentions to theorize on spontaneous interpretations and its possibilities of change require responding to two key interrogations (a) why do these spontaneous interpretations on any specific event made by individuals of different ages and different cultures resemble each other? and (b) why are they so strongly resistant to be modified? The answers to these questions up to the present time have not been, to our judgement, sufficiently satisfactory.

3.- Spontaneous Interpretations and Cognitive Constraints.

The similarities in the interpretations made by students of different cultural contexts and educational levels could be attributed to the fact that such interpretations are made by following directly the facts, without theory (Mc Closkey, 1983), or that its origin is based on non-critical generalizations derived from qualitative observations (Gil & Carrascosa, 1985). However, this would not explain the coincidence that emerge in comparing interpretations in areas where the student has little or no previous experience (electromagnetism, circuits, etc.). It is more likely, as Strike points out (1983), that misconceptions lead to misperceptions and not the other way round. Though all knowledge has its origin on reality, it is the reality, mediatized by a set of factors which lead to interpretations.

The reason why spontaneous interpretations have been so persistent has been, at times, attributed to its self-consistency (Viennot, 1979) to the fact that students feel comfortable with them (Gowin, 1983), or simply because resistance to new ideas is characteristic in human beings (Leboutet & Barrell, 1976).

The restricted number of interpretations that students make on physical situation, as well as its invariability and

tenacity, can only be understood, in our opinion, within a theory of the cognitive development, the main focus of which lies upon the formal properties of the structures and in the processes of knowledge that remain invariable in time. According to this perspective, the cognitive development would be partly guided by a complex set of constraints that would limit the type of knowledge that could be acceptable in a specific domain (Chomsky, 1980, Keil, 1981, Shepard, 1984).

This perspective on cognitive constraints allows a better understanding that certain ideas are more easily assimilable, which could even be generated spontaneously, while there are some cognitive obstacles that appear in the assimilation of other ideas that can only be obtained through specific training. Some knowledge, such as deductive reasoning or language syntax, among others, are universally developed without the need of educational efforts. However, knowledge such as newtonian mechanics, need to overcome enormous obstacles (in the sense given by Bachelard, 1942) in order to be accepted by an individual.

In this way, even though the multiple observations that the individual registers from the environment could generate multiple hypothesis, there seems to be certain constraints that guide the process of knowledge, as well as the type of acceptable structures of knowledge, which would explain that certain ideas are easily acceptable while others are tenaciously rejected.

On the other side, the fact that cognitive constraints remain practically unaltered through the development of the individual, explains the existence of a noticeable continuity between the interpretation derived from reality performed by individuals of different ages and different intellectual levels. Like Moreno (1986) points out, we have no other remedy but to admit the similarity in the intellectual functioning between the child and the adult; that means that we have to presume the existence of some unchanging functioning factors --

that have to be demarcated from the differences existing between both thoughts. It seems evident that children and adults are governed by the same system of cognitive restrictions (Keil, 1981, Carey, 1986).

4. Vines, Ecologies and Cognitive Constraints

Pines & West (1986), following Vygotsky (1962), use the vine metaphor to describe the interaction between the spontaneous knowledge, derived from the individual's own efforts to give sense to what surrounds us, and the formal knowledge, imposed by school. According to this metaphor, the spontaneous knowledge is represented like a vine that grows upwards and the formal knowledge is seen like a vine that grows downwards. -- Metaphorically speaking, the learning of science is contemplated as the intertwine of the two vines, which represents the integration of knowledge originated by both sources.

There are occasions when both vines, the one that represents the spontaneous knowledge and the one that represents formal knowledge, clash and do not intertwine. In this case it occurs what Pines & West call "conflict situation", being physics its prototype (newtonian mechanics, for example). In the case when the vines never intertwine, the knowledge remain separated in different compartments and a true and significant learning is not produced. In other occasions, both vines intertwine without difficulties, in which case the "congruent situation" occurs, being Biology its prototype. The formal knowledge serves to reinforce student's spontaneous ideas, integrating and extending them to new cases.

It is perfectly congruent, in our opinion, Pines & West's vision on the interaction of spontaneous thoughts and formal thoughts with the perspective of cognitive constraints. There are certain guides that can analyze the process of interpreting reality in a natural way (the relation cause-effect, is one of the most commonly mentioned), when the structure of knowledge which will be transmitted, follows a similar pattern this is easily accepted by the individual and both knowledges are in-

egrated. If, on the contrary, the formal interpretation -- follows another type of explanatory pattern, the structure mentioned before is rejected or, at least, it will find many obstacles before it can be accepted.

Posner, Strike, Hewson & Gertzog (1982) gave a new outlook to the possibilities of change and evolution of the knowledge possessed by the individual. They contemplate the act of learning as a process of conceptual change mediatized by a set of existing concepts in the mind of the individual and -- that, following Toulmin (1972) denomination, they called "conceptual ecology". This set of concepts affects what the student finds possible, comprehensible or reasonable, permitting the assimilation of new ideas. The "conceptual ecology" plays an important part in the selection or rejection of new ideas as well as in its comprehension (Strike, 1983). Among the characteristics of the conceptual ecology may be found analogies and metaphors, epistemological commitments (explanatory ideals, points of views about knowledge), metaphysical beliefs and other knowledges.

The perspective of cognitive constraints presents certain similarities in some aspects with the perspective of the "conceptual ecology". They both consider that learning does not consist only in acquiring direct knowledge from experience or -- indirectly from words, but that learning is always found mediatized by a set of ideas already existing in the mind of the student. The nature of that epistemic frame determines what is learnt and how it is learnt. However, we must point out some important differences: (a) the "conceptual ecology" is constituted by a set of concepts with certain characteristics (analogies, metaphors, etc); the cognitive constraints is constituted rather by a set of inferential rules on which permit organize the experience under a determined pattern. (b) "the conceptual ecology" has a series of very wide characteristics, that go from metaphors to knowledge in other fields; the cognitive constraints which we propose, cannot be so general, but, inspite of still being so weakly characterized, it would correspond to certain types of explanatory models and

rules of reasoning. (c) An important aspect of the "conceptual ecology" is its modification which permits the accomodation of new knowledge. On the contrary, the cognitive constraints are characterized by its stability, and are never totally abandoned, permitting very rarely conceptual change, in the sense of radical change in the way of interpreting reality. (d) finally, for Posner. et al (1982) "to understand learning requires understanding how the conceptions change, and for us, understanding learning requires the mechanism of the stable intellectual elaboration in the individual. There are no jumps in knowledge from zero to mastery, there are no conceptual revolutions, there are no changes of paradigm.

5.- Identifying some cognitive constraints in the spontaneous interpretations in physics.

Keil (1981) distinguishes two types of cognitive constraints: general constraints and domain-specific constraints. Even though the attention is focused mainly on the first classification, "all available evidence points towards existence of rich sets of constraints at several levels of analysis." (Keil 1981, p. 225).

One of the most notorious constraints in the investigations about the spontaneous thought made in physics is the -- attribution to cause-effect towards the relation between concepts in mechanics: force-movement or in electricity; voltage-current (Viennot, 1974, Cohen, Eylon & Ganiel, 1983, Mc Dermott, 1984). In these investigations the elaboration of the students possess the characteristics that Bunge (1979) has pointed out as typical of causal constraint: (a) conditionality, (b) asymmetry, (c) constancy and (d) productivity. For the student force produces movement. It is not a functional relation between both concepts, it overflows the frame of the semioticization to be able to attribute to the force the generation of movement (Sebastià, 1985).

The existence of this type of cognitive constraints which we could call "causal constraint" would lead to many of the

spontaneous interpretations observed, and the physical explanations that normally follow a different explanatory scheme be rejected, an example of this could be the so called the "covering law model", frequently used in physics.

Another type of general pattern of interpretations detected is the one we could name "superposition constraint", according to which the student assumes a general law of superposition that facilitates the acceptance of some physical laws (Coulomb's law for calculating electrical fields of various charges, for example) but on the other hand, impedes the comprehension of others. Strauss & Stavy (1980) analysing the concepts of heat and temperature, have found - that students in a situation of mixing water at 10°C predicted water at 20°C, using a law of superposition inexistent for intensive magnitudes. All physics teachers are also aware of the systematic mistakes made by students when applying the gauss law to calculate the electrical field between two proximate metallic plates. The student commonly calculates, when applying the gauss law, first the field corresponding to the charges of one plate and later the field corresponding to the other plate and adds them together, ignoring that the electrical field is determined by the enclosed charges in the gauss law and that a biunivocal relation cannot be established between the field and the charge, such as it exists in the Coulomb law. This systematic error could be explained also by "the superposition constraint" that makes the comprehension of the gauss law more difficult.

The above examples serve only to point out a line of inquiry that could lead to reinterpret many of the results of the investigations. Even though the type of constraints that restrict the number of hypothesis, has been studied with certain care in the learning of the language (Chomsky, 1980), in other fields, such as in the learning of physics, there is still a lot to be added to be able to establish a typology of constraints and thus determine the most appropriate way of teaching the specific topic that one wishes to transmit.

6.- Cognitive Constraints: New Obstacles in the Process of Learning Physics.

The constraints only represent, in any case, another of the multiple factors that interfere in the complex process of learning the scientific contents. The cognitive constraints, such as we understand it, fulfil an ambivalent function in the process of learning. On one side they facilitate the acquisition of certain types of knowledge, that could even be generated spontaneously, and that requires only a process of greater differentiation, but, on the other hand, they impede certain types of knowledge (quantity mechanics, for example) the structure of which may not correspond to the existent constraints in the mind of the student. This is the type of obstacle "a priori", derived from the individual and not from the object previously pointed out by Bachelard (1942).

In those cases of conflict the situation is complicated, but it is possible that the structure taught is accepted in its predictive function (making use of mathematical algorithm) but rejected in its explicative function. As Scriven (1970) has pointed out, the comprehension of a phenomenon requires at times, an explanatory structure different to the nomonological-deductive, if one wants it to be satisfactory. The vision of the logical symmetry of the positivism about the explanation-prediction of a phenomenon should, from this point of view, be released, or at least, the meaning of what we understand to be comprehension should be analysed.

When a physicist handles the concept of mass, for example, with different meanings depending on the physical situation to be analysed, classic or relativist, this means that it is possible to attend to different levels of understanding, comprehension and of utilization of the concept without entering in contradictions and without the need of conceptual revolution to pass from one situation to another. A concept, in this sense, could be understood if it can be related with -- others, according to certain rules and accepted conventions,

that means that the professional physicist can pass from the classic frame to the relativist without any trauma. The term "language game" of Wittgenstein (1966) is very appropriate to refer to the previous case, the test of comprehension required is that the individual practices the game correctly.

The educational efforts in the last decades, influenced by the logical positivism, oriented to emphasize the function of the observations in the elaboration of theories, does not seem to be well guided. Perhaps it might be convenient to propitiate the high grade of conventionalism of the theories and the different meanings of a symbol within each theory. It is possible to speak adequately of the reality with different theories, as it is also possible to speak of reality with the same property making use of different languages. If the level of comprehension to which it is hoped to be achieved is to arrive at universal premises from which any particular case can be deduced, it is improbable that this type of explanation be satisfactory for the individual. It could be more useful to distinguish two levels of comprehension: An explanatory-descriptive level conditioned partly by the cognitive constraints, and a normative-predictive level propitiated by the formal science, superposed in the individual, but without destructive interference, being utilized each on in its area, as the utilization of different languages. Possibly, the study of physics and the study of languages are not so far apart as it has been supposed up to the moment.

REFERENCES

- BACHELARD, G. 1942. La formation de l'esprit scientifique. Contribution à une psychanalyse de la connaissance objective. Librairie philosophique J. Vrin. Paris.
- BUNGE, M. 1979. Causality and Modern Science. Third edition. Dover Publications. New York.
- CAREY, S. 1986. Cognitive Science and Science Education. American Psychologist. Vol. 41, n°10, pp. 1123-1130.
- CHOMSKY, N. 1980. Rules and representations. Columbia University Press. New York.
- CLEMENT, J. J. 1982. Students' preconceptions in introductory mechanics. American Journal of Physics. Vol. 50, pp. 66-71.
- CLOUGH, E. E., & DRIVER, R. 1986. A study of consistency in the use of student's conceptual frameworks across different task contexts. Science Education. Vol. 70, n°4, pp. 473-496.
- COHEN, R., EYLON, B., & GANIEL, U. 1983. Potential difference and current in simple electric circuits: A study of students' concepts. American Journal of Physics. Vol. 51, n°5, pp. 407-411.
- ERICKSON, G. L. 1980. Children's viewpoints of heat: A second look. Science Education. Vol. 64, n°3, pp. 323-336.
- GIL, D., & CARRASCOSA, J. 1985. Science learning as a conceptual and methodological change. European Journal of Science Education. Vol. 7, n°3, pp. 231-236.
- GILBERT, J. K., WATTS, D. M., & OSBORNE, R. J. 1982. Student's conceptions of ideas in mechanics. Physics Education. Vol. 17, pp. 62-66.
- GOWIN, D. B. 1983. Misconceptions, Metaphors and Conceptual Change: Once more with feeling. Proceedings of the International Seminar: Misconceptions in Science and Mathematics. Cornell University. Ithaca. New York.
- HALLOUN, I. A., & HESTENES, D. 1985. The initial knowledge state of college physics students. American Journal of Physics. Vol. 53, n° 11, pp. 1043-1055.

- HELM, H. 1983. Do students understand the nature and role of scientific concepts?. *Proceedings of the International Seminar: Misconceptions in Science and Mathematics*. Cornell University. Ithaca. New York.
- KEIL, F.C. 1981. Constraints on Knowledge and cognitive development. *Psychological Review*. Vol. 88, n°3 pp. 197-227
- LEBOUTET, L. & BARRELL, L. 1976. Concepts of mechanics among young people. *Physics Education*. Vol. 11, n°7, pp. 462-465
- LYTHCOTT, J. 1985. "Aristotelian" was given the answer, but what was the question?. *American Journal of Physics*. Vol. 53, pp. 428-432.
- MCCLELLAND, J.A.G. 1984. Alternative frameworks: Interpretation of evidence. *European Journal of Science Education*. Vol. 6, n°1, pp. 1-6.
- MCCLOSKEY, M. 1983. Intuitive Physics. *Scientific American*. Vol. 248, n°4, pp. 122-130.
- MCDERMOTT, L.C. 1984. Research on conceptual understanding in mechanics. *Physics Today*. Vol. 46, pp. 24-32.
- MORENO, M. 1986. Ciencia y construcción del pensamiento. *Enseñanza de las Ciencias*. Vol. 4, n°1, pp. 56-63.
- MURPHY, G.L. & MEDIN, D.L. 1985. The role of theories in conceptual coherence. *Psychological Review*. Vol. 92, n°3, pp. 289-315
- NOVAK, J.D. & HELM, H. 1983. *Proceedings of the International Seminar: Misconceptions in Science and Mathematics*. Cornell University. Ithaca. New York.
- PINES, A.L. & WEST, L.H.T. 1986. Conceptual Understanding and science learning: An interpretation of research within a sources-of-knowledge framework. *Science Education*. Vol. 70, n°25, pp. 583-604.
- POSNER, G.J., STRIKE, K.A., HEWSON, P.W. & GERTZOG, W.A. 1982. Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*. Vol. 66, n°2, pp. 211-227.
- SALTIEL, E. & MALGRANGE, J.L. 1980. Spontaneous ways of reasoning in elementary kinematics. *European Journal of Physics*. Vol. 1, n°1, pp. 73-80.
- SALTIEL, E. & VIENNOT, L. 1985. ¿Qué aprendemos de las semejanzas entre las ideas históricas y el razonamiento espontáneo de los estudiantes? *Enseñanza de las Ciencias*. Vol. 3, n°2, pp. 137-144.
- SCRIVEN, M. 1970. Explanations, predictions & laws. In "Readings in the philosophy of science", Prentice Hall Inc. Englewood Cliffs. New Jersey.
- SEBASTIA, J.M. 1984. Fuerza y movimiento: la interpretación de los estudiantes. *Enseñanza de las Ciencias*. Vol. 2, n°3, pp. 161-169.
- SEBASTIA, J.M. 1985. Spontaneous interpretations in physics: the problem of motion. XX Interamerican Congress of Psychology. Caracas.
- SHEPARD, R.N. 1984. Ecological constraints on internal representation: resonant kinematics of perceiving, imagining, thinking and dreaming. *Psychological Review*. Vol. 91, n°4, pp. 417-447.
- SMITH, E.L. & LOTT, G.W. 1983. Teaching for conceptual change: some ways to go wrong. *Proceedings of the International Seminar: Misconceptions in Science and Mathematics*. Cornell University. Ithaca. New York.
- STRAUSS, S. & STAVY, R. 1983. Educational developmental psychology and curriculum development: the case of heat and temperature. *Proceedings of the International Seminar: Misconceptions in Science and Mathematics*. Cornell University. Ithaca. New York.
- STRIKE, K.A. 1983. Misconceptions and conceptual change: philosophical reflexions on the research program. *Proceedings of the International Seminar: Misconceptions in Science and Mathematics*. Cornell University. Ithaca. New York.
- TOULMIN, S. 1972. Human understanding. Vol. 1: the collective use and evolution of concepts. Princeton University Press. Princeton.
- VIENNOT, L. 1979. Spontaneous reasoning in elementary dynamics. *European Journal of Science Education*. Vol. 1, pp. 205-221.

- VIENNOT, L. 1985. Analyzing student's reasoning: tendencies in interpretation. American Journal of Physics. Vol. 53, pp. 432-436.
- VYGOTSKY, L.S. 1962. Thought and language. Hanfmann & Vaker (trans.). M.I.T. Press. Cambridge, MA.
- WHITAKER, R.J. 1983. Aristotle is not dead: students understanding of trajectory motion. American Journal of Physics. Vol. 51, n°4, pp. 352-357.
- WITTGENSTEIN, L. 1966. Lectures and conversations in aesthetics, psychology and religious belief. Barret (edit.). Basil Blackwell. Oxford.

CHILDREN'S ALTERNATIVE CONCEPTIONS ABOUT "MOLD" AND "COPPER OXIDE"

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INTRODUCTION

For the last 10 or 12 years, several research studies in science education have been done on pupils' conceptions about natural and technical phenomena prior to, during, and after formal science teaching (Novick & Nussbaum, 1981; Posner, et al., 1982 a.; Driver, et al., 1985; Osborne, et al., 1985; Cachapuz et al., 1986; Duarte, 1987; Faria, 1987; Freitas, 1987 a.).

Most of these studies are based in constructivist perspectives of behaviour, understanding and learning. These perspectives strongly refuse the empiricist paradigm of looking at the mind like a "tabula rasa" as well as the associationist paradigm of conceiving the behaviour like a set of answers to certain stimuli. As in other areas of research and action, like counseling or therapy, constructivist perspectives in learning emphasize the mental activity of all people struggling to make sense of both their world and their lives.

Although we can consider not one but various psychological constructivist approaches we must stress three decisive theoretical contributions to the strong and yet growing constructivist movement about the learning process, as follows:

- a) Kelly's theory of personal construct, which after a period of little recognition (namely in USA) begins attracting not only therapists but also educational researchers. Kelly points out that to talk about "man-the-scientist" is

to talk about a quality or a capacity of man and not about a class or a kind of man because all people are engaged in formulating personal constructs by which they look at, interpret and act upon the world in which they live in.

- b) Piagetian theory, if we refuse to restrict its focus on a rigid scale of stages of cognitive development and we stress the constructivist thrust of Piaget's genetic epistemology and his pioneer contribution to describing children's thinking and conceptions (Pope & Gilbert, 1983);
- c) Ausubel's theory of meaningful learning which emphasizes the great importance of prior knowledge in the learning process and the learner's active commitment in relating new information to what he already knows.

Being influenced by these theories, particularly by Kelly's paradigms, the alternative conceptions research area, after a promising beginning, is perhaps living a complex moment. Some researchers continue searching for alternative conceptions about this or that topic, others are more concerned with the process of interaction between prior private knowledge and curricular knowledge while others try to produce tools for promoting conceptual understanding and conceptual change. There are people more interested in doing more theoretical approaches (epistemological, psychological, philosophical) and there are others more concerned with practical aspects (curricula, didactics).

Although some researchers explicitly refer to "the danger of the whole alternative frameworks research program degenerating into a kind of mindless search for misconceptions, their frequency, etc." (Pines & West, 1986, p.598), we believe in the powerful contribution of the

different kinds of research in this area to the evolution of science education.

Based on a review of relevant research on children's alternative conceptions we investigate the following questions: a) how are children able to distinguish between "mold" of bread and copper oxide; b) how do they explain the appearance of the mold and the oxide; c) how do children classify the mold and the oxide in terms of living/non-living.

METHODOLOGY

The sample of 116 children was randomly drawn by grade from three schools in Braga: one primary school (3rd grade), one preparatory school (5th and 6th grades) and one secondary school (7th grade). The sample was constituted as follows: 30 children from the 3rd grade (15 boys and 15 girls) with an average age of 7.9 years; 27 5th graders (12 boys and 15 girls) with an average age of 10.6 years, 30 6th graders (half males, half females) with an average age of 11.7 years; 29 pupils from the 7th grade (14 boys and 15 girls) with an average age of 12.6 years. Every pupil was in his/her grade for the first time.

All the pupils were presented with questions about the "mold" and the "copper oxide" (see annexe 1) which were the first part of an individual interview about living organisms, life, death and decomposition, carried out by one of the authors in winter 1985 (Freitas, 1987). Each child took three to five minutes to answer the questions under individual interview conditions.

Based on both the individual answers given by the children to each question or set of questions and the curricular perspective contained in the syllabuses and textbooks we constructed categories each of them including a certain kind of answers.

In doing so, we also tried to make it explicit the distinction between conceptions based on curricular science and alternative ideas.

RESULTS

Table 1 shows the words used by the children of each grade in identifying the mold of bread. None of the children used either the scientific general word "fungus" or the scientific specific word "rizophus migricans". However, most of the children (80.5%) used the word "mold" which is a of both everyday language and curricular science. Such percentage is not equally distributed by the four grades. In fact, only 53.5% of the 3rd graders use the word "mold" while the remaining 46.5% either don't know how to designate it (26.6%) or employ other words like "dust", "dirt", "rust" (20.0%). The percentage of children using the word "mold" increases from the 3rd to the 6th grade going a little down in the 7th grade.

In what concerns the identification of the copper oxide, table 2 shows that none of the children use the scientific word. The most frequent words are "rust" (40.5%) and "mold" (31.9%). Other words like "dust", "mold with dirt" and "green rust" were used in a percentage of 18.1%. Nine and half percent of the pupils didn't know how to name the oxide.

Taking into account, as a whole, the words used in each case ("mold" and "copper oxide") we can see, on one hand, that only 48.4% of the children (see table 3) were able to distinguish between mold and copper oxide using words such as "mold" and "rust" (35.7%) or "mold" and "green rust" (2.6%).

On the other hand, 34.4% of the pupils confused the two entities designating both of them as "mold" (30.9%), "rust" (1.7%) or "other words" (1.8%). There are 17.2% of the pupils that can't

TABLE 1

Terms used in the identification of "mold" by grade (%)
(N=116)

TERMS	3rd Grade	5th Grade	6th Grade	7th Grade	Total
Mold	53.4	88.9	96.7	82.8	80.5
Other terms (rust, dust, dirt)	20.0	7.4	3.3	17.2	12.0
Don't Know	26.6	3.7	0.0	0.0	7.5

TABLE 2

Terms used in the identification of "copper oxide" by grade (%)
(N=116)

TERMS	3rd Grade	5th Grade	6th Grade	7th Grade	Total
Rust	36.7	59.3	40.0	27.6	40.5
Mold	26.7	22.2	36.7	41.4	31.9
Other terms (dust, mold with rust, dirt)	16.6	7.4	16.6	31.0	18.1
Don't Know	20.0	11.1	6.7	0.0	9.5

TABLE 3

Distinction between "mold" and "copper oxide" by grade (%)
(N=116)

CATEGORIES	3rd Grade	5th Grade	6th Grade	7th Grade	Total
1. Distinguishes between "mold" and "copper oxide":	33.3	51.9	56.6	51.7	48.4
1.1. using the terms "mold" and "rust"	23.3	51.9	4.0	27.6	35.7
1.2. using the terms "mold" and "green rust"	0.0	0.0	3.3	6.9	2.6
1.3. using other terms	10.0	0.0	13.3	17.2	10.1
2. Confuses "mold" with "copper oxide":	30.0	25.9	33.3	48.2	34.4
2.1. using the term "mold"	23.3	22.2	33.3	44.8	30.9
2.2. using the term "rust"	6.7	0.0	0.0	0.0	1.7
2.3. using other terms	0.0	3.7	0.0	3.4	1.8
3. Doesn't Know	36.7	22.2	10.0	0.0	17.2

$\chi^2=17.19$, $df=6$, $p<.009$ (categories 1, 2 and 3)

decide if mold and copper oxide are the same or different things. The percentage of children that are able to make that distinction increases from the 3rd to the 6th grade (33.3%, 51.9%, 56.6%) going a little down in the 7th grade (51.7%). The differences between the four grades are significant ($\chi^2=17.19$, $df=6$, $p<.009$), (see in table 3). At the same time the percentage of answers "Don't know" decreases with the grade (36.7%, 22.2%, 10.0% and 0.0%).

Regarding the explanations given by the children for the formation (appearance) of mold and copper oxide and looking at tables 4 and 5 we can see that none of the children explain both phenomena by using curricular perspectives. In fact, none of the pupils' explanations refer that: a) the mold is a microorganism (fungus) which develops in a nutritive medium (bread, for example) from reproductive cells (spores); b) copper oxide is a chemical substance formed as a result of the oxidation of the copper by an oxidant agent (usually the oxygen). All children adopt alternative conceptions based on other models. It was possible to identify three alternative models: a) the mold/oxide is a property of some objects (bread and other food / copper and metals in general); b) the mold/oxide is a result of the action of an external agent upon the object; c) mold/oxide is a consequence of a "mechanicist" interaction between an object and an external agent. Table 6 shows some of the children's answers as examples of each model referred to above.

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TABLE 4

Explanations for the appearance of "mold" by grade (%)

(N=116)

CATEGORIES	3rd Grade	5th Grade	6th Grade	7th Grade	Total
1. Curricular perspective	0.0	0.0	0.0	0.0	0.0
2. Alternative conceptions:	100.0	100.0	96.7	100.0	99.1
2.1. property of objects	33.3	22.2	20.0	37.9	28.4
2.2. product of the action of an external agent upon the object	53.3	48.1	50.0	34.5	46.5
2.3. product of the interaction between the object and an external agent	13.3	29.6	26.7	27.6	24.3
3. Don't Know	0.0	0.0	3.3	0.0	0.9

 $\chi^2=5.55$, $df=6$, $p<.475$ (categories 2.1, 2.2 and 2.3)

TABLE 5

Explanations for the appearance of "copper oxide" by grade (%)

(N=116)

CATEGORIES	3rd Grade	5th Grade	6th Grade	7th Grade	Total
1. Curricular perspective	0.0	0.0	0.0	0.0	0.0
2. Alternative conceptions:	100.0	100.0	89.9	96.5	96.6
2.1. property of objects	23.3	25.9	23.3	20.7	23.3
2.2. product of the action of an external agent upon the object	50.0	48.1	40.0	17.2	39.8
2.3. product of the interaction between the object and the external agent	23.3	25.9	23.3	51.7	31.1
2.4. other explanations	3.3	0.0	3.3	6.9	3.4
3. Don't Know	0.0	0.0	10.0	3.4	3.4

 $\chi^2=5.90$, $df=3$, $p<.116$ (categories 2.1, 2.2, 2.3 and 2.4)

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Table 6

PROPERTY OF THE OBJECTS	
PUPILS' ANSWERS	
"Mold"	• "is characteristic of the bread" • "the bread gains always that thing ..." • "as the time passes that [the mold] appears in the bread..." • "the bread is old and so ... it is like that..."
"Copper Oxide"	• "is characteristic of the iron" • "the metals gain always that ..." • "as time passes metals become like that ..." • "all old metals have that [oxide]"
PRODUCT OF THE ACTION OF AN EXTERNAL AGENT UPON THE OBJECT	
PUPILS' ANSWERS	
"Mold"	• "it is the dust that accumulates..." • "it is dirt let by insects" • "this comes from the air and accumulates upon the bread..."
"Copper Oxide"	• "it is the dirt upon the copper" • "it is the rust that comes from other things and accumulates here" • "that comes from the air and with the rain too..."
PRODUCT OF THE INTERACTION BETWEEN THE OBJECT AND AN EXTERNAL AGENT	
PUPILS' ANSWERS	
"Mold"	• "it is the sun acting on the bread" • "it is the insects and the bacteria that let the mold when they are eating the bread" • "it is the dust that infiltrates in the bread and modifies it like that..." • "mold comes from the bread (flour) by the action of heat"
"Copper Oxide"	• "it is due to the action of sun and rain in the copper" • "it is the rain that eats the metal" • "if metals are not clean, the rain and water come and disaggregate a part of the metal" • "rust is formed from the copper by the action of the air, the water and heat..."

The predominant model in both cases (mold formation and copper oxide formation) is the last alternative model referred to above - the mechanistic causal model (46.8% of the pupils for the case of the mold and 38.8% of the pupils for the oxide). The differences between grades are not significant ($\chi^2=5.55$, $df=6$, $p<.475$).

Table 7 shows children's classifications of mold and copper oxide in terms of living/non-living.

As we can easily see, only few children (11.2%) were able to make a correct classification of mold as a living organism and copper oxide as a non-living entity. A large percentage of children's (88.8%) uses alternative ideas identifying both mold and oxide either as living things (23.3%) or as non-living things (65.5%). If we group 3rd, 5th and 6th grades and compare the average percentage of these grades with the percentage of the 7th grade we found a significative difference ($\chi^2=4.86$, $df=1$, $p<.027$). This means that 7th graders, however in a small global percentage, utilize the curricular perspective more than the children of the other grades.

The criteria used by children in classifying mold/oxide as living/non-living are presented in table 8.

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TABLE 7

Classification of "mold" and "copper oxide" as living/non living by grade (1)
(N=116)

CATEGORIES	3rd Grade	5th Grade	6th Grade	7th Grade	Total
1. Curricular perspective (the mold lives and the oxide doesn't)	3.3	11.1	6.7	24.1	11.3
2. Alternative conceptions (both are living or both are non living):	96.6	88.9	93.3	75.8	88.7
2.1. both are living	3.3	25.9	33.3	31.0	23.4
2.2. both are non living	93.3	63.0	60.0	44.8	65.3

$\chi^2 = 7.36$, $df=3$, $p < .051$ (categories 1 and 2)

$\chi^2 = 4.88$, $df=1$, $p < .027$ (categories 1 and 2, grouping the 3rd, 5th and 6th
grades and after Yates correction)

$\chi^2 = 11.64$, $df=3$, $p < .009$ (categories 2.1 and 2.2)

TABLE 8

Criteria used in the classification of mold/copper oxide as
living/non living by grade (%) (N=116)

Criteria	3rd Grade	5th Grade	6th Grade	7th Grade	TOTAL
1. Cell theory	0.0	0.0	0.0	0.0	0.0
2. "Classic" characteristics of life	80.0	43.3	56.7	53.3	58.3
3. Movement	3.3	13.3	16.7	6.7	10.0
4. Other biological characteristics	6.7	16.7	10.0	3.3	9.2
5. Form, constitution and structure	6.6	6.6	3.3	3.3	5.0
6. Function and usefulness	0.0	0.0	0.0	3.3	0.8
7. State and place	3.3	16.7	30.0	10.0	15.0
8. Classificatory	3.3	3.3	6.7	10.0	5.8
9. Analogies	6.7	6.7	3.3	3.3	5.0
10. Tautology	36.7	26.7	23.3	10.0	24.2
11. Antropomorphic	6.3	3.3	0.0	6.6	4.1
12. Existence/Appearance	3.3	23.3	23.3	23.3	18.3
13. General activity	0.0	3.3	10.0	6.7	5.0
14. Other	6.7	13.3	10.0	10.0	10.0
15. None	3.3	3.3	6.7	3.3	4.2

CONCLUSION AND IMPLICATIONS

The analysis of data allows us to draw some important conclusions.

1. Regarding our first research question we can conclude that:

1.1. Only 48.3% of the children are able to distinguish between mold of bread and copper oxide;

1.2. This capacity in making such a distinction increases significantly from the 3rd to the 6th grade and decreases in the 7th grade;

1.3. Even after having been instructed about fungi (6th grade) and chemical phenomena (5th grade), a significative percentage of the pupils (33.3% of 6th graders and 48.3% of 7th graders) confuse mold with copper oxide.

1.4. Even when children are able to make the distinction referred to above they don't use the scientific words "fungus" or "oxide". In fact, although a large percentage (80.2%) can identify the mold of bread as "mold" (a word that belongs to both everyday language and curricular/scientific language), they have more difficulty in naming the copper oxide in an acceptable way. Thus they either use the common name of "rust" that they apply to iron (40.5%) or the word "mold" that comes from a certain apparent similarity with the mold of bread (31.9%);

2. Regarding to the second question it becomes clear that:

2.1. None of the children adopt the curricular perspectives for explaining the formation of both the mold and the copper oxide.

- 2.2. Almost all the pupils (99.1%) explain the formation of mold and copper oxide taking as reference one of three alternative models: a) mold/oxide as a property of some objects (28.4% and 23.3%); b) mold/oxide as a product of the action of an external agent upon the object (46.6% and 38.8%); c) mold/oxide as a product of a mechanistic interaction (24.1% and 31.1%).
- 2.3. In what concerns the utilization of such models, there are no significative differences between the four grades.
3. In regard to the 3rd research question it is possible to state that:
 - 3.1. Only a small percentage of the pupils of all grades (11.2%) was able to classify the mold as a living organism and the oxide as a non-living thing. The remaining 88.8% of the pupils classified both the mold and the oxide either as living organisms or as non-living things.
 - 3.2. However, the great majority of the children (65.5%) shows an "inanimistic" tendency, i.e. state that mold is an inanimate entity; only 23.3% of the children show traits of animism in classifying the copper as living organism.
 - 3.3. The differences among grades in adopting the curricular perspectives versus alternative conceptions between grades are significant only if we compare the percentages of 3rd graders with the average of the percentages of the other grades.
 - 3.4. We can also stress that the graders in our sample are significantly less animistic (and so more "inanimistic") than 5th, 6th and 7th graders.

- 3.5. The most frequently used criteria in classifying mold and copper oxide as living/non-living things are the "classic characteristics of life" (58.3%), "tautology" (24.2%), "existence/appearance" (18.3%); none of the children utilize "cell theory based" criteria.
- 3.6. Children's conceptions about life and living organism are more a problem of alternative models used to make the distinction between animate and inanimate things rather than a stage dependent spontaneous evolution from animism to an "adult" concept of life, as Piaget postulated.

If you want to go further ahead, inserting this specific study about mold and oxide in a wider context, and draw some more general conclusions, we must consider the learner's placement within a constructivist perspective. In figure 1 we try to represent how learner's knowledge is placed and interacts with other kinds of knowledge.

A constructivist perspective about knowledge and learning acknowledges the idea of everyone (scientist, teacher, pupil or citizen) constructing his/her own private understanding either directly about the reality or about some part of public knowledge. Everyone's private knowledge is, in the end, a result of one's effort to make sense of his/her world and his/her life. In the world, as well as in life, things are not divided into disciplines or topics but related to one another and integrated as a whole. So, the teaching and learning process must begin with general and integrated concepts, models and procedures. The inevitable disciplinary approach can only be done bearing in mind integrated general schemes and always returning to them. Taking the topic of this study we think that the Portuguese curricular perspective of emphasizing, in the first years of

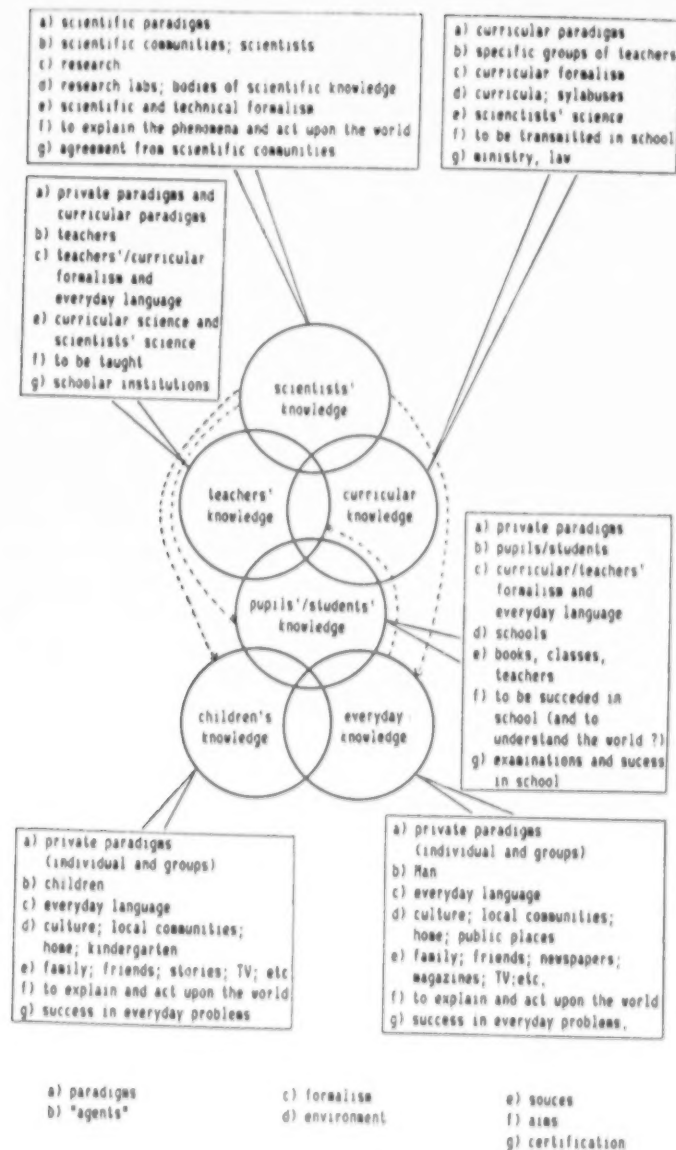


FIG. 1

school, the differences between living and non-living may not help children to understand the concepts of living being, non-living being, life, death, decomposition of matter, etc.. In our opinion living and non-living, as well as organic and inorganic matter should be approached in parallel, by discussing not only the differences, but also the similarities. The unity of matter must be approached in the curricula since the first years of school.

Struggling to make sense of the world they live in, children use very often causal explanation models (Andersson, 1986) or look at the dynamic and interactive phenomena as if they were properties of things (Driver et al., 1985). This is clear if we look at the models used by the children of our study when explaining the mold/oxide process formation. Taking the causal explanations models we would like to stress our curiosity about a possible relationship between such causal schemes and the generalized existence of logical fallacies such as assuming that events which follow others are caused by them (post-hoc reasoning), or imputing causal significances to correlations (Jungwirth, 1985; Sequeira & Freitas, 1987). We also believe that circular reasoning (tautologies) is another important fallacy, related to children's alternative conceptions (see table 8), which is sometimes tolerated if not reinforced by curricula, by some school textbooks and even by teaching activities. Such assumptions allow us to suggest some major implications for science education. School teaching and learning activities must consider such generalized models of conceptual (or descriptive) knowledge and procedural knowledge. However, to change some causal explanations for some specific phenomena or facts is not enough - we need to change the stereotyped kinds of reasoning, like post-hoc reasoning or correlational fallacies.

Everyday language is a reality that can't be ignored. Several times either the word used in everyday language for designating something is different from the one used in curricular science or the same word has different meanings in the everyday world and in school context. We believe that science teachers must have this reality into account. The everyday language must be recognized by schools and teachers but not in the sense of either accept its characteristic words or mechanically substitute the common words by the "scientific" ones. The problem is to establish the correspondences as well as the discrepancies between the two languages and to stress the importance of learning how to use each of them.

REFERENCES

- Andersson, B. (1986). The experiential gestalt of causation: a common core to pupils' preconceptions in science. *European Journal of Science Education*, Vol. 8, nº 2, 155-171.
- Ausubel, D.P., Novak, J.D. & Hanesian, H. (1980). *Psicologia Educacional* (2ª Ed.). Rio de Janeiro: Editora Interamericana Ltda.
- Brumby, M.N. (1982). Student's perceptions of the concept of life. *Science Education*, 66(4), 613-622.
- Cachapuz, A.F. & Ribeiro, M.G. (1986). Identificação de versões privadas de conceitos de Química no ensino secundário. *Boletim da Sociedade Portuguesa de Química*, 23(11), 21-36.
- Champagne, A., Klopfer, L., Desena, A. & Squires, D. (1981). Structural representation of students' knowledge before and after science instruction. *Journal of Research in Science Teaching*, Vol.18, nº2, 97-111.
- Driver, R. (1981). Pupil's alternative frameworks in science. *European Journal of Science Education*, Vol.3, nº1, 93-101.
- Driver, R. (1983). *The pupil as scientist?* Milton Keynes: Open University Press.
- Driver, R., Guesne, E. & Tiberghien, A. (1985). *Children's Ideas in Science*. Milton Keynes: Open University Press.
- Driver, R. & Bell, B. (1986). *Student's thinking and learning of science: a constructivist view*. Leeds: Center of Studies in Science and Mathematics Education.
- Duarte, M. (1987). *Ideias alternativas e aprendizagem de conceitos*. Dissertação de Mestrado, Universidade do Minho, Braga.
- Faria, M. (1987). *O impacto de ensino individualizado nas ideias intuitivas das crianças*. Dissertação de Mestrado, Universidade do Minho, Braga.
- Freitas, M. (1987 a.). *Concepções científicas alternativas de crianças portuguesa acerca da vida, morte e decomposição dos seres vivos*. Dissertação de Mestrado, Universidade do Minho, Braga.
- Gilbert, J.K., Osborne, R.J., Fensham, P.J., (1982). Children's science and its consequences for teaching. *Science Education*, 66(4), 623-633.

- Hewson, P.W. (1981). A conceptual change approach to learning science. *European Journal of Science Education*, 3(4), 383-396.
- Hewson, M.G. & Hewson, P.W. (1983). Effect of instruction using student's prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching*, Vol.20, n°8, 731-734.
- Looft, W.R. & Bartz, W.H. (1969). Animism revived. *Psychological Bulletin* 71, n°1, 1-19.
- Novak, J. & Gowin, B. (1986). *Learning how to learn*. London: Cambridge University Press.
- Novick, S. & Nussbaum, J. (1978). Pupil's understanding of the particulate nature of matter: a cross-age study. *Science Education*, 62(3), 273-282.
- Novick, S. & Nussbaum, J. (1981). Pupils understanding of the particulate nature of matter: a cross-age study. *Science Education*, 65, 187-196.
- Nussbaum, J. & Novick, S. (1982). A study of conceptual change in the classroom. Paper presented at the annual meeting of the National Association for Research in Science Teaching, April 1982.
- Osborne, R. (1980). Some aspects of students' views of the world. *Research in Science Education*, 10, 11-18.
- Osborne, R.J. & Wittrock, M.C. (1983). Learning science: a generative process. *Science Education*, 67 (4), 489-508.
- Osborne, R.J. & Freyberg, P. (1985). *Learning in science: the implications of children's science*. London: Heinemann Publishers.
- Piaget, J. (1976). *The child's conception of the world*. New Jersey: Littlefield, Adams & Co.
- Pines, A. & West, H.T. (1986). Conceptual understanding and science learning: an interpretation of research within a sources-of-knowledge framework. *Science Education*, 70(5), 583-604.
- Pope, M. & Gilbert, J. (1983). *Constructive Science Education*. Paper presented at Personal Construct Psychology Conference, Boston, July.
- Posner, G.J., Strike, K.A., Hewson, P.W. & Gertzog, W.A. (1982). Accomodation of scientific conception: toward a theory of conceptual change. *Science Education*, 66 (2), 211-227.
- Sequeira, M. & Freitas, M. (1987). "Death" and "decomposition" of living organisms: children's alternative conceptions. *Actes du 11^{ème} congrès de l'ATEE, Toulouse, Editions Privat*.

Appendix I

Interview guide (First part - mold and copper oxide problem)

Children are shown a piece of bread with mold and a small copper plaque oxidated in several points.

Look carefully at both this piece of bread and this copper plaque.

(pointing to the mold in the bread)

1 - What is this ?

(pointing to the copper oxide)

2 - And this ?

3 - How do you explain the appearance of that thing you named as (1) ?

4 - And of that thing you named as (2) ?

5 - The (1) is a living being or a non-living being ?

6 - Why do you say that the (1) is a living/ non-living being ?

7 - And the (2) is a living or a non-living being?

8 - Why do you say that the (2) is a living/ non-living being ?

(1) - name given by the child to the mold of bread.

(2) - name given by the child to the copper oxide.

What Besides Conceptions Needs to
Change in Conceptual Change Learning?

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Over the past ten years, a large body of research has described numerous examples of widely held beliefs about natural phenomena that differ fundamentally from contemporary scientific explanations of them. These alternative frameworks, misconceptions, naive theories or naive conceptions are more than interesting observations or obstacles to be overcome. They point to the nature of learning in science and to the challenge of learning with understanding.

The importance of these naive conceptions derives from the central role our conceptions play in perception, comprehension, problem solving and learning. They form a directing and interpretive framework within which we literally construct our knowledge and experience from information available in our memories and environment. Thus, the fact that most learners bring to the study of science conceptions which differ from and often conflict with those underlying the information they encounter creates a considerable challenge. The rather straightforward comprehension that occurs when appropriate conceptions are available cannot take place. In order for the subject matter to be understood, the conceptions one has must be changed. This creates the problem of conceptual change as described by Toulmin (1972), Posner, Strike, Gertzog and Hewson (1982), and others (e. g., Carey, 1986).

The research on naive conceptions has revealed that in many cases only a minority of students accomplish this kind of learning. Some misinterpret instruction in terms of their naive conceptions while others find it difficult to make much sense of instruction and resort to memorization to meet the demands of instruction.

It is clear from the student conceptions research that students' naive conceptions are an important factor in learning (or failing to learn) science with understanding. However, as a number of researchers have noted, there is more to conceptual change learning than changing conceptions per se. For example, Viennot (1983) discusses ways in which "students' spontaneous reasoning" differs from that of physicists. She points out that the range of problems to which students apply their

notions does not cover the same domain as that of the physicist, and that while "a concept is well defined in physics, always designated explicitly by the same word, ... in spontaneous reasoning students are usually not conscious of the 'notion' they use and may call it, sometimes indifferently," by several different names.

Soloman (1983) contrasted features of students' "life-world knowledge" and knowledge based on the "formal explanations that we teach in school." She points out that, in contrast to science knowledge, lifeworld knowledge is "inconsistent and context bound" and "is not symbolic." Her central point is that students develop two very distinctive "worlds of knowledge."

These examples illustrate that helping students to function more like scientists in their acquisition and use of scientific knowledge involves more than changing specific conceptions. The purpose of this paper is to explore what else may need to change. I will address this goal in three ways. First, I will describe several such aspects from our own research program at Michigan State University. Next I will relate this work to the idea of a conceptual ecology (Posner, et al, 1982). Finally, I will discuss how such changes might be addressed, drawing on some preliminary pilot work.

Some Other Things that Change

In this section I shall refer to several studies carried out by my colleagues and I at Michigan State University, highlighting aspects relating to aspects of knowledge that seem to require change along with more obvious changes in students' conceptions. These aspects include:

1. The kinds of explanations students construct and prefer,
2. Students reasoning about the conservation of matter, and,
3. Student goals and strategies for instructional tasks.

Student Explanations--Empirical Circularity

The importance of these two aspects of student thinking emerged from two earlier studies and became central foci in recent one. The nature of students' explanations emerged as an issue in a two stage study of science teaching at the fifth-grade level (Smith and Anderson,

1984). The first stage was a naturalistic study of 14 teachers, nine of whom were using an inquiry-based science program (SCIIS or SCIS II) and five of whom were using a text-based program (Exploring Science, published by Laidlaw). During the second stage of the study we developed interventions in which we provided instructional materials designed to help teachers become more aware of and help students change their naive conceptions.

We observed the inquiry program teachers teaching a unit on plants as producers in which students were expected to develop the conception that plants make their food by using light to combine carbon dioxide and water. The textbook unit dealt with light and vision. That unit addressed the idea that we are able to see objects when some of the light reflected by them is detected by our eyes. Thus, both units' intended outcomes involved children using abstract, unobservable processes to explain observable events. However, a common pattern on both our pretests and our posttests as well as in class discussions was for children to offer as explanations, statements which were essentially a reiteration of the observation to be explained. For example, students explained that the plants didn't continue to grow in the dark because they needed light to grow. The students seemed satisfied with such empirical circularity as a form of explanation. Thus, they had little motivation to integrate the new ideas into their thinking about the phenomena. The students in the inquiry program tended to think that the point of the experiments and the unit was to demonstrate the empirical relationship between light and plant growth.

As a result of our findings concerning this empirical circularity in the students' explanations, change in students' explanations was addressed explicitly in later interventions (Roth, 1983; Roth and Anderson, 1985). Roth (1983) expressed this contrast in her student text as follows:

How can we explain these observations? A good explanation for a science experiment does not just tell what you saw. A good explanation gives a reason to explain why something happened. Sometimes you have to think about things you cannot see to come up with a good explanation of what you do see. (p.7)

Reasoning About Conservation of Matter

A contrast between naive and more scientific thinking about conservation of matter emerged very clearly in a subsequent study in which we examined the teaching and learning of three life science topics in the classrooms of thirteen seventh grade teachers. Student thinking about the topics of photosynthesis, cellular respiration and matter cycling indicated that many students did not view matter as being conserved in the phenomena related to these topics (Smith and Anderson, 1986 and 1987). Such thinking was particularly apparent in the matter cycling topic.

Nonconservation of matter was manifested in two distinct naive conceptions of matter cycling (Figure 1). In the more naive conception, matter appeared and disappeared in various natural processes that occur under proper conditions (Naive II in Figure 1). In this view, for example, organisms require food to grow. However, the food is not viewed as being transformed in some way to become part of the growing organism. Rather, having food is simply a necessary condition for the natural process of growth to occur. Similarly, dead organisms naturally "rot away" over time. Thus, students may be able to trace the cycle of events but do not view matter as cycling at all.

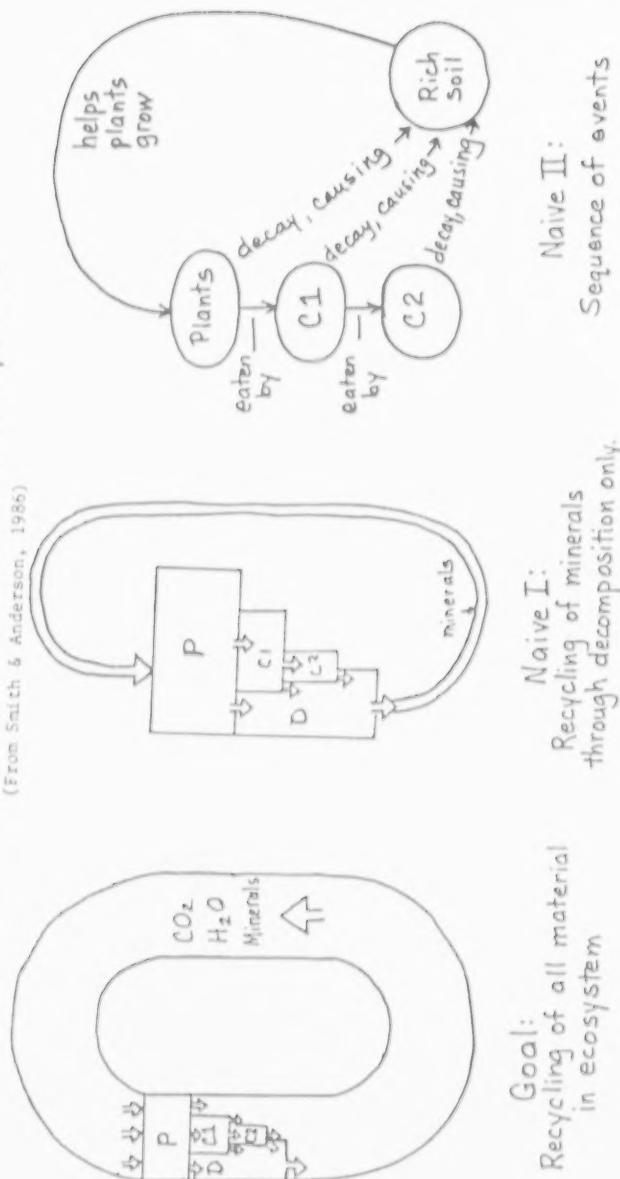
In a less naive conception (Naive I in Figure 1), matter is viewed as moving through food chains as organisms become food for other organisms and some of the food becomes incorporated into the bodies of the eating organisms. However, in this view other food gets used for energy. Some of these students can trace food through the digestive tract and the bloodstream to the cells. But there it apparently ceases to be matter. Also, the process of decay is viewed as converting dead organisms into minerals which recycle. Although these students view some matter as cycling through the ecosystem, they clearly do not view matter as necessarily conserved in the process.

This study suggests that development of student understanding of photosynthesis, cellular respiration and matter cycling requires a level of commitment to conservation of matter in what scientists view as chemical changes. A subsequent study (Hesse, 1987) directly examined the role of conservation reasoning in student conceptions of chemical

Figure 1

Issue: Movement of matter in ecosystems

(From Smith & Anderson, 1986)



change. That study also examined the role of students' explanatory preferences.

Conservation Reasoning, Explanatory Preferences and Conceptions of Chemical Change

The studies referred to above indicated that intended changes in students' topic specific conceptions were intertwined with issues concerning the kinds of explanations they tend to construct and broader principles such as the conservation of matter. These issues were the focus of a study of student conceptions of chemical change (Hesse, 1987).

This study involved about one hundred of Hesse's high school chemistry students. Hesse's data sources included a combination of written explanations of demonstrated phenomena, written judgments about the acceptability of their explanations, stated preferences for a balanced equation or everyday analogy as a means of making their explanations more acceptable, and interviews which further probed student thinking about the demonstrated phenomena and their reported judgments.

Among the key findings in Hesse's study were:

Only a small minority of students explained the phenomena in terms of chemical theory. The rest regularly substituted everyday materials and energy for chemical substances or focused on some visible aspect of the change they were asked to explain.

Few of the students were "chemically conserving mass" in their explanations. However, some did exhibit conservation reasoning when they interpreted the changes as "intricate forms of physical transformations like freezing or evaporation."

There was a "preponderance of analogical thinking" among the students. For some, this seemed to be the only option available since they had little functional chemical knowledge. However, even many of the students with the most chemical knowledge indicated a preference for analogies. Students seemed to believe that chemists' explanations said essentially the same thing using bigger words.

In discussing these results, Hesse noted that both analogical and chemical theory explanations have proper form according to Toulmin's (1961) formulation. That is, both relate the phenomenon to be explained to something judged more simple and self explanatory. They differ, rather, in content. While the chemist prefers explanations that are reductionist, and appeal to chemical theory, the students prefer explanations which draw on the familiar.

Hesse drew a comparison between the students' preference for familiar analogies and Aristotle's use of the life cycle of plants and animals as an "explanatory ideal." He pointed out, however, that students do not exhibit commitment to any particular analogy. Furthermore, the students' analogies frequently draw students attention to surface features of the phenomena and away from unobservable features that students might in other circumstances be assisted to consider. Thus, while there may be potential value in the use of analogies, typical student use of them is problematic. Hesse argued that if students are satisfied with their analogical explanations, their motivation to seek alternatives will be low.

Conservation reasoning and chemical theory seem interdependent in that, without chemical theory, conservation of mass appears implausible in many phenomena. On the other hand, without a commitment to conservation, there is little reason to consider the possibility of unobserved reactants and products.

Hesse concluded that both conservation reasoning and explanatory ideals need to be explicitly addressed in the curriculum along with, and explicitly related to, chemical theory. He further argued that this treatment must take explicit account of students' naive conceptions in all three areas.

These arguments are consistent with Posner, Strike, Gertzog and Hewson's requirements for conceptual change (1982). Dissatisfaction with existing conceptions and plausibility of an alternative are viewed as important requirements to be fulfilled if learners are to seriously consider the alternative, to say nothing about coming to adopt it over the existing one.

Student Strategies and Goals

Roth (1984) found that a conceptual change-oriented text was useful in helping fifth-grade students change their conception of plants' source of food. To gain a deeper understanding of the effects of such texts, she conducted a study which examined both the students' reading processes and changes in their conceptions of photosynthesis and food for plants (Roth, 1985a & 1985b). This study involved eighteen seventh-grade students using one of three alternative texts. Two of the

texts were chapters from existing textbooks while the third was an experimental text designed to explicitly address the common student misconceptions about food for plants identified in earlier studies. The texts were of comparable lengths (about 3400 words) and reading level.

A stratified random sampling procedure was used to assign 18 middle school students to groups so that each group contained two students reading above, at, and below grade level according to Metropolitan achievement test results. Each student read one of the three texts over a three day period. Following each reading session, each student was interviewed to obtain information about both their reading strategies and their ideas about photosynthesis and food for plants. The students were also pre- and post tested using written tests similar to those used in our previous studies.

The results of the posttests and interviews indicated that all but one of the experimental text group reflected understanding of the goal conceptions while only one of the twelve students in the conventional text groups did. Although the experimental text was dramatically more effective, the most important contribution of this study was the insight gained into the strategies students adopted in reading the texts. The strategies identified were:

1. Reading for conceptual change. Characterized by:
 relating text ideas to own experiential knowledge and to real world phenomena,
 recognizing and actively thinking about central text ideas that conflict with personally held ideas,
 recognizing conceptual confusion while reading,
 willingness to change misconceptions to resolve conflicts,
 reading goal of making sense of text ideas and using them to change personally held ideas.
2. Overrelying on prior knowledge and ignoring text knowledge. Characterized by:
 decoding to find familiar words,
 relying on prior knowledge to answer both text questions and questions about the real world, largely ignoring text ideas,
 reading goal of performing the assigned task.

3. Overrelying on details in the text - separation of prior knowledge and text knowledge. Characterized by:

- focusing on details in text, most often specialized science vocabulary,
- using details to answer text questions,
- not attempting to relate details to one another or to real-world phenomena,
- reading goal of successfully completing assigned task.

4. Overrelying on facts in the text with an addition notion of learning - separating prior knowledge and text knowledge. Characterized by:

- accumulating facts from the text,
- remembering ideas in no particular order and placing equal emphasis on details and main concepts,
- prior knowledge used to answer questions about the real world,
- reading goal of memorizing facts.

5. Overrelying on prior knowledge and distorting text to make it compatible with prior knowledge. Characterized by:

- attempting to make sense of text and integrate text ideas with prior knowledge,
- distorting or ignoring some of the text information to make it fit with their ideas,
- using prior knowledge and new information to answer text questions and questions about the real world,
- reading goal of adding information to what they already knew.

The use of alternative strategies by students of different reading levels using different texts is summarized in Table 1. Strategies 2 and 3 can be characterized as task completion strategies. The students did not seem to be concerned with learning at all. They were used by the below-grade level readers in the conventional text groups. Strategy 4 is a learning strategy, but only in a rote learning sense. New information was not integrated into students' prior knowledge. This strategy was used by two of the four at-grade level readers in the conventional text groups. The other at-grade level readers and 3 of the 4 above-grade level readers in the conventional text groups generally used strategy 5. These students attempted to make sense of the text, but selected and distorted text information to fit with their own prior ideas. Only strategy 1 was effective in helping the students change their misconceptions and develop an understanding of the goal

TABLE 1

STRATEGY USE¹ BY STUDENTS OF DIFFERENT READING LEVELS USING DIFFERENT TEXTS

Reading Level	Conventional Texts Strategy #	Strategy Type (Frequency)	Experimental Text Strategy #	Strategy Type (Frequency)
Below grade	2 & 3	Task completion (4/4)	1	Conceptual change sensemaking (2/2)
At Grade	4	Non-integrative learning (2/4)	1	Conceptual change sensemaking (1/2)
	5	Egocentric sensemaking (2/4)	1, 2, 5	Mixed (1/2)
Above Grade	5	Egocentric sensemaking (3/4)	1	Conceptual change sensemaking (3/3)
	1	Conceptual change sensemaking (1/4)		

¹ Strategies listed are those used predominantly over the three sessions. Some use of other strategies was not uncommon, especially in the first session.

conceptions. However, only one student using the conventional texts used this strategy. About half used non-sensemaking strategies and most of the rest used an egocentric sensemaking approach.

All but one (an at-grade level reader) of the students in the experimental text group came to use a conceptual change strategy, including all the below-grade level readers! This is particularly remarkable considering that the students' only source of information was the text. The claim was not made that the students had developed this strategy to the point where they could use it with conventional textbooks. However, the study does demonstrate that, with appropriate support, even below grade-level readers can use much more effective strategies for learning, even when text is a primary resource.

This study illustrates a different kind of change required, or at least highly desirable and beneficial, for conceptual change learning to take place, namely change in the goals and strategies with which the students approach instructional tasks. The study also demonstrates that conceptual change-oriented text, based on adequate knowledge of common student conceptions and ways of thinking about a topic, can be a very useful resource in helping to bring about such changes.

Discussion

This paper addressed the question what, besides conceptions, needs to change in conceptual change learning? In my review of our work at Michigan State, I have described the following "other" kinds of changes:

1. Changes in students' explanatory tendencies, preferences, and ideals.
2. Changes in students' reasoning concerning conservation of matter.
3. Changes in students' goals and strategies for addressing instructional tasks.

Conceptual Ecologies: Toward a Synthesis

The idea that conceptions are not the only things that need to change in conceptual change learning is not new. Other researchers have described features that distinguish expert from novice knowledge (e.g., Viennot, 1983). A very useful general formulation of this argument is the notion of the "conceptual ecology" in which a conception exists or must come to exist. This idea is based on the work of Toulmin (1972)

and has been elaborated by Posner, Strike, Gertzog and Hewson (1982), Hewson (1981), and Strike and Posner (1985). In this section I will consider how the kinds of changes I have described relate to Strike and Posner's (SP) formulation of the features of an conceptual ecology (Figure 2).

Conservation of Matter. This principle might be considered a "metaphysical concept of science" in the SP formulation. However, in modern science it is not a universal principle since matter is not conserved in nuclear changes. If it is not included as a metaphysical concept, there seems to be no place for it except "Other knowledge." Perhaps there should be a category, 'Related knowledge or conceptions.' The SP formulation has no category which recognizes the role that other knowledge within a field plays in determining the status of a given conception. "General principles" might be a subheading, providing a place for principles like conservation of matter.

Explanatory tendencies and preferences. This aspect has an obvious place in the framework, "Explanatory ideals." However, I suggest that the label be expanded to include tendencies and preferences to reflect the less consistent nature of students' naive explanations. That is, the development of explanatory ideals is itself a change from more naive patterns of explanation.

Goals and strategies for addressing school tasks. The relation of this kind of change to a conceptual ecology is more complex than that of the others. I think that it is more appropriate to represent the goals and strategies as related to (or not related to) the conceptual ecology rather than as a part of it. The task completion goals and strategies (2 and 3 above) have little relation at all to changes in conceptions or conceptual ecologies (at least to those dealing with the phenomena of concern in science). The fact memorization goal and strategy make only minimal connection with the conceptions (which for these learners are almost exclusively naive, experientially based). On the other hand, the sensemaking goals and strategies have as their focus changes in the conceptions that exist within the conceptual ecology. However, there may be ways in which changes in these goals and strategies are related to aspects of the conceptual ecology.

Figure 2
Features of a Conceptual Ecology
(From Strike & Posner, 1985)

1. Anomalies. The character of the specific failures of a given idea are an important part of the ecology which selects its successor.
2. Analogies and metaphors. These can serve to suggest new ideas and to make them understandable.
3. Exemplars and images. Prototypical examples, thought experiments, imagined or artificially simulated objects, and processes all influence a person's intuitive sense of what is reasonable.
4. Past experience. Conceptions which appear to contradict one's past experience are unlikely to be accepted.
5. Epistemological commitments.
 - a. Explanatory ideals. Most fields have some subject matter specific views concerning what counts as a successful explanation in the field.
 - b. General views about the character of knowledge. Some standards for successful knowledge such as elegance, economy, parsimony, and not being excessively ad hoc seem subject matter neutral.
6. Metaphysical beliefs and concepts.
 - a. Metaphysical beliefs about science. Beliefs concerning the extent of orderliness, symmetry, or nonrandomness of the universe are often important in scientific work and can result in epistemological views which, in turn, can select or reject particular kinds of explanations. Beliefs about the relations between science and commonplace experience are also important here.
 - b. Metaphysical concepts of science. Particular scientific conceptions often have a metaphysical quality in that they are beliefs about the ultimate nature of the universe and are immune from direct empirical refutation. A belief in absolute space or time is an example.
7. Other knowledge.
 - a. Knowledge in other fields. New ideas must be compatible with other things people believe to be true.
 - b. Competing conceptions. One condition for the selection of a new conception is that it should appear to have more promise than its competitors.

particularly in epistemological commitments and metaphysical beliefs about science as illustrated in Table 2.

Table 2
Epistemological and Metaphysical Beliefs Associated with
Alternative Strategies and Goals

Issue	Type of Goal and Strategy			
	Task completion	Non-Integrative	Sensemaking	
			egocentric	concept change
Awareness of of own relevant ideas	Not aware of science topic	Not aware of having relevant ideas	Aware of having relevant ideas	Aware of having relevant ideas
Relation between scientific and own ideas	Not aware of science topic	My facts are right or wrong	Essentially the same	May conflict
How science knowledge is acquired	Science is doing tasks	Add facts	Add ideas and details	Change and add ideas, details
Applicability of science ideas	Science has little to do with the real world	Facts have little to do with the real world	Science ideas apply to the real world	Science ideas apply to the real world

I have not attempted a comprehensive analysis of what other than conceptions must change in conceptual change learning. Rather, I have examined three specific examples that have arisen in our research on specific conceptions. Hopefully, my formulation of the issue and discussion of implications for the general notion of a conceptual ecology will stimulate further efforts along these lines. These examples of other kinds of changes also raise psychological, curricular, and instructional issues. I address these, at least implicitly, in the last section of the paper.

"Other" Kinds of Changes as Curricular Goals

It appears that for students who approach instructional tasks with the kinds of non-sensemaking goals and strategies described by Roth, changes in the third category are prerequisite to changes in the first two as well as to changes in specific conceptions that might be addressed by instruction. No claim was made that the changes in student goals and strategies in the Roth study were permanent or general. Rather, students had sufficient support through the tasks and information in the text to enable them to adopt a conceptual change

sense making approach. Even this limited change, however, raises important issues. Could sustained instruction bring about a more permanent and general change in students' approach to instructional tasks? Can students be taught to use a conceptual change sense making approach to learning using conventional textbooks?

Over the past year, I have been collaborating with a reading researcher in pilot work to examine these issues (Dole & Smith, 1986). To date we have only developmental work to report and little in the way of empirical evidence that our approach will succeed. However, a description of this approach is a way of illustrating the kind of support we believe students will probably need in making such changes.

Our pilot work has been informed by perspectives from social psychology (e.g., Wertsch, 1985). From this perspective, complex tasks are initially performed cooperatively by the teacher and students with control gradually being shifted to the students over time. Modeling, guided practice with feedback and other forms of "scaffolding" are important in students' early performance. This approach is illustrated in the work of Palincsar and Brown (1984) in the teaching of reading comprehension. Anderson (1987) has recently discussed its potential contributions to science education. Collins, Brown, and Newman (in press) have formulated a version of this work in what they term "cognitive apprenticeship."

In addition to the use of modeling and guided practice with feedback, our approach includes three elements to support students in conceptual change sensemaking: 1) the establishment of an instructional task structure that is conducive to sensemaking, 2) explicit introduction of a strategy for use in reading, and 3) explicit instruction on aspects of student knowledge of themselves as knowers and learners and of textbooks (metacognitive knowledge).

Establishing an instructional task structure conducive to sensemaking. A central influence on students' approach to learning is the nature of the tasks established in instruction. Our approach involves building a unit around a small number of central questions, posed in everyday language and requiring explanations of familiar

phenomena. Such questions help establish a meaningful purpose for study of the unit and a framework for selecting and organizing information. For example, our pilot work with the topic of cells was organized around the questions:

What are living things made of?

How do living things grow?

What happens to the food we eat?

Tasks that required students to construct representations (verbal or written summaries, concept maps, etc.) of ideas encountered in the text or to explain specific phenomena were assigned in each lesson. Finally, A synthesizing task was used at the conclusion of the unit, requiring students to pull together information from the unit and their own ideas to construct answers to the central questions. In our pilot work this involved students working in groups to construct posters with verbal and pictorial information. Alternatives might include constructing a concept map representation or a section to be included in a class science book.

The kind of task structure illustrated here is essentially an invitation to approach the reading and related tasks as a sensemaking activity. However, at the outset, only a portion of the students appear able to approach the tasks in this way. The other elements in our approach are designed to help the majority do so.

Cognitive strategies. One of the key findings in the Roth study was that some of the students, usually those reading above grade level, made sense of what they were reading by interpreting it in terms of their own prior ideas, leading to misinterpretations and selective attention. To help overcome this egocentric sensemaking, we devised a strategy for use during reading. This strategy involved students monitoring their own and text ideas relevant to questions explicitly or implicitly addressed in the text. We explored various forms of such a strategy including the use of a think sheet on which students could write a question, their own initial ideas, text ideas, and the main idea that they ended up with.

Metacognitive knowledge. Through discussion, teacher presentations, and examples encountered, we attempted to develop student awareness of the following ideas about themselves and the textbook:

They already have ideas of their own relevant to the topic of study.

Their ideas may differ from the ideas presented by the author in the text.

The text may not always provide answers to their questions, may be unclear, or may contain errors.

Summary. Instruction along the lines just described addresses several kinds of goals including changes in students' goals and strategies for performing instructional tasks as well as more specific conceptual learning. As implied in this description, for such learning to occur, it must be experienced in the ongoing life of the classroom. Initially students will need considerable support. Over time, the level of support needed should decrease. How far this might go for most students is one of many issues that need to be addressed by future research and development efforts. However, the prospect that such changes might be accomplished for most students in science classrooms is an exciting prospect.

Explanatory Tendencies and Preferences

The central questions and associated task structure described above places a heavy emphasis on explanation. The frequent occurrence of student explanations provides opportunity to address their improvement as a curricular goal. We found in our pilot work that the limitations of the empirical circularity type of explanation became apparent to many students as soon as they were pointed out.

While taking class time to deal with the nature of explanations and the relative advantages and disadvantages of naive versus more scientific conceptions will probably be viewed by many as taking time away from learning science content per se, Hesse's study suggests that in some cases at least there may be no alternative. If students are to develop a preference for explanations using chemical theory over a distanced analogy with some familiar phenomenon, they will need experience in which they develop a scientific explanation that they

find both intelligible and plausible. Furthermore, they will probably need to come to understand some of the limitations in the distanced analogy as an explanation. To accomplish these conditions, considerably more emphasis will need to be placed on the development and discussion of student explanations of particular phenomenon. For example, the burning of a piece of wood could serve as a prototypic chemical change and serve as the focus for extended consideration. In conventional instruction, many students never really develop a very good chemical explanation of such a phenomenon. Thus, it can hardly offer an attractive alternative to an analogy such as, "its shriveling up, like growing old". Consider the following hypothetical teacher responses that might follow such an explanation:

Teacher: Your explanation compared burning to another phenomenon, a person growing old. You pointed out that in both cases, the something "shriveled up." Is burning like growing old in any other sense?

Teacher: We could observe that the wood shriveled up. Does the comparison with growing old add anything to what we already observe? Does that comparison do anything to tell us why the wood shrivels up or turns black?

Teacher: A good scientific explanation should go beyond what you can already observe in a phenomenon. Scientists try to develop explanations that explain why something happens in addition to describing what happens. Such a discussion may help students to become dissatisfied with this type of explanation and more willing to consider explanations based on scientific theory.

The development of explanations for prototypic phenomena can also provide a context for meaningful introduction of the issue of conservation of matter. The discussion of burning, for example, can lead to a line of questioning dealing with the materials that are involved in the phenomena and the materials that are left. At some point, the question can be raised as to whether or not the materials that are left weigh the same or more or less than the materials that were there originally.

In summary, in the context of tasks requiring the construction of explanations of phenomena, teachers can model and help students engage in a process in which they attempt to relate ideas from the text to phenomena in the real world and to their own ideas. The nature of good explanations and the application of principles such as the conservation of matter can be addressed in this context in a meaningful way.

Much remains to be done in furthering our understanding of conceptual change sense-making, the development of student explanatory tendencies, preferences and ideals, and in the development of student reasoning about principles such as the conservation of matter. Further, it remains to be seen how helpful our particular approach will be in bringing about changes in these areas. I hope, however, that this description of our preliminary developmental efforts will lead others to think constructively about these and other changes that may be important in conceptual change learning.

REFERENCES

- Anderson, C. W. (1987). Three perspectives on cognition and their implications for science teaching. Paper presented at the annual meetings of the American Educational Research Association, Washington, D. C.
- Carey, S. (1986). Cognitive science and science education. American Psychologist, 41(10), 1123-1130.
- Collins, A., Brown, J.S., & Newman, S.E. (in press). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In Resnick, L.B. (ed.), Cognition and Instruction: Issues and agendas. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Dole, J., & Smith, E. L. (1986). Development of teaching and learning strategies for conceptual change learning from science textbooks. Proposal for an All University Research Initiation grant, Michigan State University, East Lansing, Michigan.
- Driver, R. (1985). Beyond appearances: The conservation of matter under physical and chemical transformations. In Driver, R., Guesne, E., & Tiberghien, A. (Eds.), Children's ideas in science. Philadelphia: Open University Press.
- Hesse, J.J. (1987). Student conceptions of chemical change. Unpublished doctoral dissertation. East Lansing, MI: Michigan State University.
- Hewson, P. W. & Hewson, M. G. A. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. Instructional Science, 13, 1-13.
- Palincsar, A.S., & Brown, A.L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. Cognition and Instruction, 1(2), 117-175.
- Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66(2), 211-228.
- Roth, K.J. (1983). Food for Plants. East Lansing, MI: Michigan State University, Institute for Research on Teaching.
- Roth, K.J. (1984). Using classroom observations to improve science teaching and curriculum materials. In C.W. Anderson (Ed.), Observing science classrooms: Perspectives from research and practice. Association for the Education of Teachers in Science Yearbook. Columbus, OH: ERIC/SMEAC. (77-102).
- Roth, K.J. (1985a). The effects of science texts on students' misconceptions about food for plants. Unpublished doctoral dissertation, Michigan State University.
- Roth, K.J. (1985b). Conceptual change learning and student processing of science texts. Paper presented at the annual meetings of the American Educational Research Association, Chicago, Illinois.
- Roth, K.J., & Anderson, C.W. (1985). The power plant. East Lansing, MI: Michigan State University, Institute for Research on Teaching.
- Smith, E.L., & Anderson, C.W. (1984a). The planning and teaching intermediate science study: Final report (Research Series No. 147). East Lansing, MI: Michigan State University, Institute for Research on Teaching.
- Smith, E.L. & Anderson, C.W. (1986). Students' conceptions of matter cycling in ecosystems. Paper presented at the annual meetings of the National Association for Research in Science Teaching, San Francisco, California.
- Smith, E.L., & Anderson, C.W. (1987). The effects of training and use of specially designed curriculum materials on conceptual change teaching and learning. Paper presented at the annual meeting of the American Educational Research Association, Washington, DC.
- Soloman, J. (1983). Thinking in two worlds of knowledge. In Helm, H. & Novak, J. D. (Eds.) Misconceptions in Science and Mathematics. Proceedings of the International seminar, Cornell University, Ithaca, NY.
- Strike, K.A., & Posner, G.J. (1985). A conceptual change view of learning and understanding. In L. West and A.L. Pines (Eds.), Cognitive Structure and Conceptual Change. New York: Academic Press.
- Toulmin, S. (1961). Foresight and understanding. Great Britain: The Anchor Press, Ltd.
- Toulmin, S. (1972). Human Understanding. Princeton, NJ: Princeton University Press.
- Viennot, L. (1983). Natural tendencies in analysing students' reasoning. In H. Helm and J.D. Novak (Eds.), Misconceptions in Science and Mathematics. Ithaca, N.Y.: Cornell University.
- Wertsch, J. (1985). Vygotsky and the social formation of mind. Cambridge, MA: Harvard University Press.

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Studies of children's conceptions have a long history, mostly in clinical settings. One of the earliest systematic attempts to examine children's conceptions of the physical world was carried out by Piaget (1929, 1930). Over the years a variety of research methods has been developed to probe the meanings children have for the words they use in explaining things that happen in the world. They include both clinical interviews which focus on specific aspects or problems (Nussbaum & Novak, 1982; Osborne & Gilbert, 1980) and more general interviews which probe what a person knows about a topic (White and Gunstone, 1980). Once obtained, the information could be represented in a suitable format, such as a semantic network or grid, which was seen to represent the child's cognitive structure (Posner and Gertzog; 1979). Driver and Erickson (1978); and Erickson (1984) have analyzed the similarities and differences in these studies and established that there is much commonality in terms of the research methods developed.

Typically, researchers in science education have addressed the notion of constructed meaning by analyzing students' cognitive beliefs about a narrow set of concepts or topic area. Scant and insufficient attention has been given to the values that underly children's thinking about the world. Researchers try to distinguish between cognitive and affective domains, but in fact, they can not be separated. One way of attempting to capture some of the

complex interplay between cognition and affect is by the construct of an orientation. In this study, an orientation means a tendency for an individual to understand and experience the world through an interpretive framework, embodying a coherent set of beliefs and values. These orientations are thought to be deeply rooted aspects of our conceptual system and not easily accessible with normal probing techniques such as pencil and paper tests or even conventional interview techniques. One of the ways of understanding these broad intellectual commitments is to look more carefully at the nature of metaphorical thinking in children.

This paper makes no attempt to thoroughly review the advantages and disadvantages of the various research methods, but rather describes the metaphor interview in detail to reveal its subsumed techniques and its richness in illuminating the complexities of a child's belief system. The research itself is part of a larger study in the general area of research on childrens' thinking, which supports the view that childrens' prior beliefs and values need to be taken seriously and incorporated into the instructional setting (Snively, 1983, 1986). The first section provides a brief overview of the larger study, the purpose of instruction, the case setting, and the findings. The second section reviews the metaphor interview as developed by Beck (1978, 1981), and outlines the four metaphor interviews constructed for the analysis of the students' orientations

and beliefs. Last, the implications of the metaphor interview for educational research and instruction are discussed, as well as issues that this work leaves unanswered and possibilities for future research.

Brief Overview of the Study

The purpose of the larger study was to explore the relationships between the students' orientations towards the seashore, their beliefs about specific ecological relationships, and their experiences during science instruction. The study involved the collection and analysis, by metaphor and literal interviews, of students' orientations and beliefs before and after instruction. By looking for patterns in the students' responses, six different orientations were identified (scientific, aesthetic, utilitarian, spiritual, recreational, and health and safety), as well as a diversity of beliefs about specific seashore relationships (tidal cycle, habitat, predator-prey, food chain, community, pollution, conservation, etc). In addition, observations were made during classroom instruction and interviews were conducted with selected individuals in the school and the community to aid in the analysis of the students' orientations and beliefs.

The participants consisted of a class of grade 6 students in a small coastal town in British Columbia, which will be given the pseudonym "Salmon Cove". A native Indian community is located at one end of the cove and a community

largely of European extraction is located at the other end of the cove. Commercial fishing is the main source of income for both Native and non-Native families. It was expected that the presence of both native and non-native students in the study would result in the presentation of a wide range of orientations towards the seashore, and a diversity of beliefs about specific seashore relationships. The main criterion used in the selection of a grade 6 class was the ability of students at that age level to express their ideas in metaphor interviews. Within the class, six target students were selected for intensive study: the student with a preferred scientific orientation (Dan), a preferred utilitarian orientation (Jimmy), a preferred aesthetic orientation (Mary), a preferred spiritual orientation (Luke), a preferred recreational orientation (Anna), and a student with no preferred orientation (Sharon).

The primary focus of instruction was to introduce a basic set of ecological concepts focused around seashore relationships. In order to increase a students' knowledge of beach ecology, the teacher attempted to use instructional metaphors which were sensitive to the student's preferred orientation identified prior to instruction. A second purpose of instruction was to enhance the student's ability to view the seashore from a variety of orientations.

Results of the pre-instructional interviews showed that while all of the students used several orientations to

describe the seashore, some students used one orientation predominantly. Only a few students held beliefs which were quite similar to accepted science ideas; most students held beliefs which were quite different. For most students, there was a reasonably strong relationship between their orientations and the nature of their beliefs about specific seashore relationships.

Results of the post-instructional interviews show that for all of the students there was an increase in knowledge about basic seashore relationships, and a decrease of beliefs inconsistent with accepted science ideas. This increased knowledge was accompanied in most students by a willingness to use a scientific orientation more frequently. This new knowledge appeared to be relatively stable six months after instruction, implying that it was firmly integrated into the students' cognitive system. The fact that many students still used orientations which they possessed prior to instruction, and that for some students these orientations were more elaborated, provides evidence that they were willing and able to view the seashore from a variety of orientations.

The Use of Metaphor to Uncover Meaning

For several years Beck (1978, 1981) has been exploring the use of metaphor as an indicator of cultural values in an anthropological setting. She developed a metaphor interview technique which could be used to identify the conceptual frameworks of a culture. However, Beck emphasized the

values of people towards family relationships and the concept of ethnicity, for example, paying less attention to the implications of values for specific beliefs and practices. The larger study attempted to establish how the students' beliefs and values were related.

From May 1980 to October 1981, a series of five small pilot studies were conducted to sharpen the research questions and develop a research method. The problem was not one of extending or adapting some existing metaphor interview, but of developing a unique set of metaphor questions in which the analysis of the students' orientations was the central purpose.

The Metaphor Formats

In attempting to develop and use metaphor interviews, three problems were encountered: the interviews had to be designed to 1) explore the students' orientations towards the seashore, 2) explore the students' beliefs about specific seashore relationships, and 3) be appropriate to the language development of young children. In developing the metaphor interviews the basic interview techniques described by Beck (1978; 1981) were followed, but ideas from Lakoff and Johnson (1980) about metaphorical systematicity were incorporated to construct the interview questions. Following Lakoff and Johnson, the very systematicity which allowed the students to comprehend one aspect of a concept in terms of another will necessarily hide other aspects of the concept. For example, in the "Seashore is a playground"

metaphor, the students were encouraged to focus on some aspects of the recreational aspects of the seashore concept, and encouraged not to focus on aspects of the other orientations of the seashore. The interview questions were designed to highlight and hide a range of orientations towards the seashore: e.g., the image "painting" was selected to highlight an aesthetic orientation, a "town" to highlight a scientific orientation, a "church" to highlight a spiritual orientation, a "playground" to highlight a recreational orientation, and a "pin cushion" to highlight a health and safety orientation. For example, the first type of interview asked each respondent to explore the following question:

If the seashore were one or more of the following, which one or ones would it be:

factory	church
painting	playground
town	pin cushion

WHY?

At every point the students were asked to explain "WHY?" they had selected a particular metaphor over others. THE QUESTION "WHY?" WAS ESSENTIAL, as this procedure generated the most interesting and useful information. Although the actual type of metaphor chosen was noted, and for some students did yield some interesting patterns, the "WHY?" query was the key to the technique's success since it

indicated the respondent's reasoning for choosing a particular metaphor.

The metaphor formats contained three additional types of questions that depended on metaphorical thinking. The second type of question asked each respondent to explore fifteen different seashore animals, objects, events and conditions. For example:

If a clam were one or more of the following, which one or ones would it be:

vacuum cleaner	legend
potlatch	necklace
dance	

WHY?

OR If the sun were one or more of the following, which one or ones would it be:

jewel	factory
furnace	lamp
gift	

WHY?

The response was intended to indicate the student's reasoning towards selected animals, objects, events and conditions at the seashore.

The third set of questions asked each student to explore twelve different imaginary questions. For example:

If you were a bird, would you be a:

raven	seagull	eagle
-------	---------	-------

WHY?

861

860

OR If you were a boat, would you be a:

sail boat ferry boat fishing boat

WHY?

This interview generated some of the most imaginative and useful material. The students found the metaphor questions in this interview the easiest to elaborate. They appeared to enjoy discussing their metaphor choices, possibly because of the single metaphor construction, and because the questions resembled the children's play at the seashore wherein they "become" a bird, or a fish, or a boat.

The fourth set of questions asked each respondent to explore nine metaphoric dyads. Each dyad contained two types of questions that depended on metaphoric thinking. The metaphors were chosen to represent contrasting relationships: story teller is to a story, or character is to a story, or listener is to a story. The respondents were asked to decide which of the three pre-selected images was best suited to symbolize his or her own relationship to the seashore. For example:

I am to the seashore, as a

- story teller is to a story - character is to a story
- listener is to a story

WHY?

In addition, the students were asked to indicate directionality. If the students' relationship to the seashore was like a story teller to a story, which element of the dyad would the respondents call the story teller and

which the story, and WHY? Some students found the metaphor questions in this interview to be difficult to think with, possibly because of the double metaphor. Nonetheless, all of the students gave some explanation for their choices. See Erickson (1983) for the complete set of metaphor questions.

During the interviews the students were asked to select the best metaphors from amongst a range suggested. Since it is difficult to keep several images in mind at once, the options provided were written on three-by-five-inch white cards. In some of the interviews involving seashore animals a pictorial black-and-white line-print was provided on the card. When possible, the native Indian word for the animal, object or event was printed inside parentheses beside the English word. The students' full verbal responses were recorded on audiotape.

Since metaphors are often sophisticated, it could be argued that children would have great difficulty in using language metaphors when interviewed, especially children of different cultural backgrounds. In the present study, however, all the metaphors were formed from common nouns, and the imagery was not difficult for elementary students to grasp. Most of the imagery was taken from a range of familiar household or community objects: e.g., painting, bicycle, pin cushion, jewel, curtain, door, house. A few "atypical" metaphors were added to probe for variations in metaphor style: e.g., spaceship, robot, submarine.

Simple metaphors frequently become imbedded in sea lore and everyday conversation--"cranky as a crab," "crusty as a barnacle," "smells fishy," "clam-up," "ship-off." This kind of trite expression was avoided. Following Beck (1978), the interest in choosing metaphors for use in an interview was in stimulating the respondents to project "deep-set" concepts onto exterior forms in an imaginative way.

Also, by talking to various students and native elders in Salmon Cove, and by exploring the community and noting its special features, metaphor questions could be constructed which were grounded in the physical and cultural backgrounds of students living in a small native Indian and non-native coastal community in British Columbia. For example, the metaphors "pot-luck dinner" and "potlatch" were seen to be better utilitarian metaphors than the metaphors "dinner" or "supper" or "feast." The metaphor "cannery" was seen to be a better utilitarian metaphor than "factory," since a fish cannery was an integral part of everyday life in Salmon Cove. The metaphors "totem pole" and "legend" were viewed as appropriate spiritual metaphors, and the metaphors "blackberry bush" and "pin cushion" were viewed as appropriate health and safety metaphors, and so on.

Also, during the pilot study interviews, students were asked to generate their own metaphors for the seashore. One might think that imagery generated by the students would be

more revealing than those generated by the researcher. But this advantage was counterbalanced by the difficulty most students had thinking up metaphors for themselves. Most students could not give a metaphor, or gave partial explanations which could not be categorized into orientations. Even after completing the interviews and with coaching, most students gave back metaphors that had already been used during the interviews.

Finally, after selected interview sets, each student was asked to choose the metaphor response which best described how he or she viewed the seashore. It was hoped that by comparing the students' preferred responses (their first, second, and third choice responses), and by noting their own metaphors for the seashore, that a distinction could be made between the students' preferred orientations prior to instruction, and the effect of instruction on the students' preferred orientations after instruction.

Identifying The Students' Orientations

The following illustrates a typical student response within each of the six orientations:

Utilitarian
The seashore is a factory.
It's got crabs, fish for
canning.

Jimmy

Scientific
The seashore is a town.
All the animals that live
at the seashore. They
all grow up there. The
rocks being for the
animals to hide under.

Dan

Aesthetic

The seashore is a painting.
It just looks like a painting
an artist would paint.

Mary

Spiritual

The seashore is a legend.
There's a legend about
this man who became wild
and he could do things
that animals could do...

Luke

Recreational

The seashore is a playground.
You don't have to work. Do
what you want. Could be a lot
of fun; looking for animals,
crabs, finding shells. It's
peaceful.

Mary

Health and Safety

There's the barnacles and
the sea urchins that
could poke if you were to
fall on them.

Jimmy

A certain consistency in the reasons students gave could be seen to persist across their particular choices of metaphor. For example, "The seashore is a painting" metaphor frequently resulted in an aesthetic response. "The seashore is a factory" metaphor frequently resulted in a utilitarian response. "The seashore is a pin cushion" metaphor usually elicited a health and safety response. On the other extreme, a certain consistency in the orientations students preferred could be seen to persist across their choices of metaphor. For example, the students with a preferred aesthetic orientation tended to stress the aesthetic aspects of the seashore regardless of the type of metaphor image selected. Notice how three different students stressed different orientations for the metaphor, "The seashore is a gift":

Scientific

The seashore is a
gift. Because of
the many things
that live there.

Dan

Aesthetic

The seashore is a
gift. We can enjoy
the water. The way
it looks pretty.

Mary

Recreational

The seashore is a
gift. Because
children can play on
it, swim in the
water, and throw
rocks.

Jimmy

Some students, more than others, responded to a particular metaphor with a complex concept of the seashore. For example, in a single response notice how one student stressed a range of orientations for the gift metaphor:

It was given to us to use. And we use it!
We're supposed to use it properly. It's
like a special gift that was given to us
to use. The way fishermen use it for fish.
People use it to learn about the animals.
And for fun too.

Sharon

Notice the obvious utilitarian aspects: "We use it. . . The way the fishermen use it for fish." There are recreational aspects as well: "And for fun too." Also, notice the scientific or intellectual aspects: "People use it to learn about the animals." Perhaps there is even a concern for conservation: "We're supposed to use it properly." And overall, there are subtle spiritual or moral aspects that may not be immediately obvious: "It was given to us to use. We're supposed to use it properly. It's like a special gift that was given to us to use." Hence, a student's response depends upon the complexity of thought the metaphor stimulates and upon other characteristics of the students.

The metaphor interviews worked effectively to enable

the identification of the different orientations used by the students. While all of the students exhibited several orientations when describing the seashore, some students used one orientation predominantly, and some showed a greater mix of orientations. Although some combinations of orientations would appear to be more probable than others, the data suggest that any combination of orientations is possible.

The metaphor "The seashore is a playground" used in the interviews, illustrates how an attempt was made to comprehend and represent the students' orientations to the seashore. The focus of thinking in this metaphor, the "seashore," has very different kinds of experiential bases to a child growing up in a large urban center such as Vancouver, a child growing up in an isolated coastal community in British Columbia, and a child growing up on a white sandy beach in the South Pacific. Similarly, the word "playground" has very different kinds of experiential bases to a child whose only space for recreation is a city street, a child who has access to a large vacant lot or an adventure playground, and a child who frequents Disneyland. It is not that there are many different "playgrounds," rather, the concept of playground enters the child's experience in many different ways and so gives rise to many different metaphor responses.

The metaphor interview has a kind of ambiguity in the context of an experience. The student is asked to compare

two terms: the term "seashore," of which something is being asserted, and the term "painting," used metaphorically to form the basis of the comparison. Words have a range of meanings, some may have new or original meanings while others may have familiar meanings. The force of the metaphor depends on the respondent's uncertainty as he or she wavers between the two meanings. The students' response should be viewed as the meaning, either consciously or unconsciously, that the respondent gives to the metaphor. The student's emerging response depends on the complexity of thought the metaphor stimulates and upon multiple characteristics of the student's thought.

The students' interpretation of the term "playground" may be based on different kinds of experiences, as shown in the responses of two different students:

The seashore is a playground. All the kids play on the beach. You find crabs, make stuff, teeter totter, make masks from wood, make sticks to hold fish.

Jimmy

The seashore is a playground. I play at the beach a lot; catching animals, looking at them. I fly my kite.

Dan

Some of the experiential bases of Jimmy's metaphor response is obvious. For example, "All the kids play on the beach . . . teeter totter" is an obvious statement of the recreational aspects of the seashore. "You find crabs, make stuff, make sticks to hold fish" is an obvious statement of

the utilitarian aspects of the seashore. While some of the experiential bases of Jimmy's metaphor responses is obvious, some of the experiential bases of Jimmy's response is not obvious. The statement "making masks from wood" is an implicit statement about the spiritual aspects of the seashore that is grounded in cultural experience. Stronger corroborating evidence comes from other examples of attaching spiritual significance to the seashore. For illustration, during the field study phase, the following data were collected from the Salmon Cove native Indian teachers:

Jimmy is a full-status native Indian living with his very traditional native Indian grandparents. The grandfather dances a lot in the bighouse. Jimmy was a good dancer in the primary grades.

In the above data Jimmy's reference to "making masks from wood" is most likely a statement about the spiritual aspects of dancing in the bighouse and attending potlatches. This datum suggests that some metaphor responses can only be categorized and adequately represented when additional information concerning the student's social and cultural background is taken into consideration.

There is another way the students' metaphor responses illustrate why it is important to categorize in terms of entire domains of experience. Jimmy's reference to "you find crabs" is very different from Dan's reference to "catching animals and looking at them." At first, the two statements appear similar in their experiential bases.

However, important experiential differences become clearer when additional information is taken into consideration. For example, from the metaphor interviews Jimmy makes numerous references to "finding crabs", "catching fish", "checking his crab traps", "eating them" and "making a lot of money". By sharp contrast, Dan makes numerous references to "finding crabs", "catching animals", "looking at them", "learning about them", and "letting them go". Also, when asked to draw a picture of a crab at high tide and at low tide, Jimmy was the only student to draw an edible crab (Dungeness crab), while Dan drew the common purple shore crab. Jimmy's reference to "finding crabs" is most likely a statement about the utilitarian aspects of an experience, while Dan's reference to "catching animals and looking at them" is most likely a statement about the scientific aspects of an experience. This is important, because many times clues to a student's own understanding of a reference were found when it was related to similar references in the student's entire set of metaphor and literal responses, and to interviews with elders and school officials in the community of Salmon Cove.

Identifying the Students' Beliefs

In attempting to identify and analyze the students' beliefs about specific seashore relationships before and after instruction, the interviews has to be designed to 1) explore the students' beliefs about specific seashore relationships, and 2) use accepted science concepts related to beach ecology as a standard to compare and contrast the

students' ideas and beliefs. For example, the metaphor "The seashore is a hotel" was used to highlight the concept of habitat, "A seagull is a robber" to highlight the concept of predator-prey, "The sun is a factory" to highlight the concept of energy.

After looking for patterns in the students' responses, a number of specific beliefs were identified which students held about seashore relationships. The beliefs listed below illustrate the responses students gave to the metaphor questions:

Death

The seashore is a graveyard. Some whales go up on the beach when their time is up. They go up on the beach and die.

Habitat

A cobblestone is a hotel. Under the rocks there's all sorts of little things: crabs, sand fleas, eels.

Predator-prey

A starfish is a can opener. It can open clams, mussels, and many other shellfish.

Recycle

A crab is a garbage collector. It picks up anything that's dead to eat, because it's scavenger.

Energy

The sun is a factory. It seems like a factory because it's producing things, like helping plants grow.

Community

The seashore is a town. It's like the little animals are all together in a community. Like under a rock it's just like there are different animals: shore crabs, limpets, hermit crabs, eels, snails, all living together.

When attempting to comprehend and adequately represent the students' beliefs, their metaphor responses were categorized according to the criteria that best described the basic set of ecological concepts. While some of the students' responses are explicit statements about specific concepts

and are reasonably easy to categorize, other responses are implicit statements and are more difficult to categorize.

The Metaphor Interview as a Research Tool

Metaphor interviews enable researchers to examine aspects of the cognitive system which are often masked by more conventional approaches. In addition to probing for beliefs, the metaphor interviews probed what the students think is desirable and how they felt. The metaphor interviews did more than probe for single beliefs or single values or single emotions. By asking the students to project responses onto metaphors in an imaginative way, the students were less likely to be consciously aware of the beliefs and values that they were communicating. The metaphor interviews allowed the study of how, in most situations, a complex cluster of beliefs, values and feelings influenced the formation of the students' response. One of the more useful features of the metaphor interview is that it allowed an analysis of "preferred" beliefs and "preferred" orientations. It allowed an analysis of the relationship between the students beliefs about the seashore, their preferred orientations, and the type of instruction that occurred.

The students' metaphor responses also illustrate another very important aspect of children's conceptions of the seashore--that is, the importance of the two-sided nature of their thinking. On the one hand there is extensive use of sensory-based experiences (eg., the

references made to "playing at the seashore", "finding crabs", "looking at them"), while on the other hand the children used images embedded in specific social or cultural context (e.g., the reference to "making masks from wood", "legends", and "totem poles"). The students' metaphor responses allow researchers to get at modes of thinking, that are grounded in the students' previous physical, social, and cultural experiences with a richness of detail.

The students' metaphor responses express the particular qualities of experience. What are the particular qualities of Dan's scientific mode of inquiry and his intimate relationship to the seashore? What are the particular qualities of Mary's enjoyment of the peaceful and pretty aspects of the seashore? What are the particular qualities of Luke's relationship to the supernatural animals and events in nature? In revealing these expressive qualities through metaphor interviews, educators have the opportunity to participate vicariously in the lives of students, to acquire an empathetic understanding of these situations that are important in the lives of their students.

What characteristics of the metaphor interview allowed the illumination of beliefs and orientations? One of the most important characteristic of the metaphor interview is that it is non-directive. The metaphor question suggests, it doesn't define. Hence, the students have to define their preferred relationship to the seashore. There is a connection between the characteristics of metaphorical

thinking, which are essentially relational in nature, and the responses obtained by metaphor interviews. The metaphor interview allowed the analysis of relationships such as: 1) a student's comprehension of the relationships among concepts, 2) a student's own relationship to the phenomenon under study, and 3) a student's relationship with others in social and cultural situations. The students' metaphor responses illuminated whether the students' relationship to the seashore is passive, active, dominating, positive, negative, and so on.

Metaphor interviews may have implications for multi-cultural education by allowing researchers to understand the thinking of students with different social and cultural backgrounds. In this study, both Jimmy and Luke are native Indians. Both students have writing, reading, mathematics, and science skills which are well below grade level, as evidenced by their report card grades and achievement test scores. Yet both students gave responses which allowed an analysis of their beliefs and orientations. The metaphor interview is one possible assessment tool that takes into account the linguistic and socio-cultural background of the child.

Metaphor interviews could be used in large urban centers, in rural settings, and in isolated coastal fishing or native communities. They can be linked to a sampling strategy to provide important qualitative data that is holistic and episodic. The discourse of students struggling

to increase their understanding of science concepts adds humanistic understanding to quantitative research.

Metaphor Interviews and Future Research

A variety of questions about metaphor interviews needs to be explored. How can metaphor interviews take into account linguistic differences? Do students of different ages and developmental levels need different metaphor questions? Can metaphor interviews be quantified?

Clearly, some students may have more ability than others in responding to metaphor questions about particular aspects of reality. Metaphor interviews need to be developed for students with different metaphorical abilities and experiences. To do this, the abilities and preferences to express ideas in metaphorical fashion need to be explored for students of different ages, sexes, and social and cultural groups. For example, in the present study, a single metaphor question such as: "I would be an eagle, a raven or seagull" appealed to students of all ages, especially to primary children, whereas a double metaphor question: "I am to the seashore as a driver is to a car, a passenger is to a car, a mechanic is to a car", seemed to be difficult for students under grade five. There are metaphor interview techniques which seem to be more appropriate for students at different developmental levels. This finding is consistent with other research indicating that children's ability to handle more demanding metaphor comprehension tasks increases with age (Johnson, 1983; Marschark and Nall,

1983; Vasniadou and Ortony, 1984). In addition to exploring a wider range of language metaphor questions, researchers need to explore a range of non-verbal metaphor formats as well--the use of pictures and role-playing in probing for preferences. Such research is currently lacking in science education.

In spite of the apparent desire of many researchers to try and assign numbers to any construct, there needs to be caution in attempting to quantify the students' metaphor responses. Because orientations have a certain stability and coherence, they appear easy to classify into categories. In reality, orientations seem to be quite context dependent and the researcher must have appropriate knowledge and experience with the contexts to categorize the students' responses. Hence, the task of simply counting responses in a given category will be neither very informative nor particularly valid. The richness of the metaphor interview is its potential to illuminate personal perceptions, feelings, and value preferences.

The development of a sensitive metaphor interview and the analysis of responses depend on an understanding of the respondent's physical, social and cultural experiences, the curriculum as presented, and so on. For instance, in the present study, this analysis requires knowledge of the social and cultural milieu of Salmon Cove, as well as fishing methods and the state of commercial fishing in British Columbia, the instructional concepts of interest,

and knowledge and experience of the seashore. This suggests that the analysis of data is not a simple coding schedule which can be picked up in a 30 minute training session. An inter-rater reliability category system may be possible and desirable in some future studies, if it presupposes a holistic understanding of complex situations. A sensitive coding schedule would require a careful examination of the contributions of context to the students' metaphor response.

As the use of a metaphor interview described in this paper rests on data collected through a small interview sample, the need for more extensive research is obvious. As such, it suggests that educators in all subject areas need to explore this research frontier. The use of a metaphor interview is one important way educators can monitor and resolve conflicts between the beliefs and values that students bring to instruction, and the concepts taught in the classroom.

BIBLIOGRAPHY

- Beck, B. (1978). The metaphor as mediator between semantic and analogic modes of thought, Current Anthropology, 19, (1).
- Beck, B. (1981). The use of a metaphor interview in ethnic research: Variations in the concept of ethnicity. Paper presented at the Canadian Ethnic Studies Association Conference.
- Driver, R. & Erickson, G. (1978, April). The study of students' conceptual frameworks in science: Some theoretical and empirical considerations. Paper presented to the American Educational Research Association in Montreal.
- Erickson, G.L. (1984). Some issues on cognitive structure and cognitive change in science education. A paper presented at a symposium on Cognitive Structure and Cognitive Change at the annual meeting of the American Education Research Association, New Orleans, La.
- Erickson, G.L. (1983). Student frameworks and classroom instruction, Proceedings of the International Seminar on Misconceptions in Science and Mathematics (pp. 39-50). Cornell University, Ithica, New York.
- Lakoff, G. & Johnson, M. (1980). Metaphors we live by. Chicago: University of Chicago Press.

- Nussebaum, J. & Novick, S. (1982). The challenge of student alternative frameworks to teachers and researchers: a position paper. Jerusalem: Israel Science Teaching Centre, The Hebrew University.
- Osborne, R.J. & Gilbert, J.K. (1980) A method for the investigation of concept understanding in science. European Journal of Science Education, 2, 311-321.
- Piaget, J. (1929). The child's conceptions of the world. London: Routledge and Kegan Paul.
- Piaget, J. (1930). The child's conception of physical causality. New York: Harcourt, Brace and Co.
- Posner, G. & Gertzog, W. The clinical interview and the measurement of conceptual change. Paper presented to the Annual Meeting of The American Educational Research Association, San Francisco, Ca.
- Snively, G. (1983). The use of metaphoric interviews in educational research: Children's beliefs and orientations towards the seashore. Paper presented to the Pacific Circle 7th Annual Conference in Vancouver.
- Snively, G. (1986). Sea of Images: A study of the relationships amongst students' orientations and beliefs, and science instruction. Unpublished Ed.D. Dissertation, University of British Columbia.

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Rational personal constructivism

Even at the First Symposium, now four years into the past, it was clear that there were many different approaches to the study of children's ideas about scientific matters. In any early pre-paradigmatic field of social research the way to start, it seemed, was to listen attentively, with respect, and with as little in the way of preconceived ideas as possible, to the words of the subjects themselves. Educational researchers from many countries had indeed been doing just this, and the collection of papers which resulted is still a rich repository of primary research data.

But this was not the whole story. The very respect which is so essential for an ethnographic study had itself engendered a theoretical perspective. Heated discussion between the symposium participants concerning the use of labels such as "misconceptions", "preconceptions", and "alternative frameworks" showed that different schools of interpretation had begun to surface. The ethnographic methodology, because it used the comments of individual students, and was often carried out by those trained in science, gave rise to a strong rational personal constructivist position. This was first seen, perhaps, in a paper about conceptual change by

Strike and Posner (1982) where the authors based their argument on the rationality of students - "being rational has primarily to do with how we move from one view to another". This notion that each child operated quite logically moving from one theoretical position to another according to the weight of experimental evidence, was probably derived from the Personal Construct Theory of Kelly (1955): Pope (1982), for example referred to the students' "causal explanatory systems" and Osborne and Bell (1983) to "Children's Science".

There is a strong anecdotal tradition of thought, or "gedanken", experiments in physics (Helm and Gilbert 1985), which is popularly exemplified by the story of the young Einstein imagining what it might be like to chase after a beam of light at a speed approaching that of light itself. There are a few other such historical stories, each one memorable and insightful especially when used in the rational tradition of "reductio ad absurdum" to produce valuable new knowledge. Perhaps they are actually more famous than they deserve to be, and encourage us to recognise a comparable rationality in the fluid inventions of students. The child who approaches anywhere near this kind of rationality in their own musings is rare indeed. Interviewers in the ethnographic tradition certainly met with plenty of homespun ideas but, as the talk continued, the students often moved from one to another, at some times obligingly constructing a new one from scratch to satisfy

the questioner. More than one researcher has had the experience of the previous day's interviewee rushing up with cries of "I have worked out a better answer to your question!"

Personal rationality was thought to be applied to the students' own motor experiences, although no examination of customary knowledge of familiar actions was made directly. Evidence certainly turned up in the interview transcripts where students made reference to what they had seen or done, and this was accepted as the raw data from which their subsequent constructions flowed. But how or when this modelling from observation or action was made did not then seem to be an important part of the research programme. Now however we can see that verbalised ideas are at a far remove from raw experiences both because they need to be constructed in words and probably talked over with others, and also because the repetition of customary physical acts, through their sheer familiarity, often seem to make them opaque to explanation. Thus craft or body knowledge may simply remain within the memory as non-verbal "Tacit Knowledge" (Polanyi 1958) which is hard to relate to the personal construction of ideas.

The rational personal aspect of knowledge was also being challenged by awkward empirical results. Careful exploration of how students cope with problem solving (eg Viennot 1979 and Champayne and Klopfer 1980) had shown

clearly that students did not apply their ideas consistently, even when the scientific problems being discussed were very similar. In a theoretical paper based on South African data Hewson (1981) accepted that taught scientific ideas could oust, be defeated by, or even live alongside the childrens' own notions. If rationality did not govern the young students' subsequent learning of science was it right to assume that these persistent and widespread pre-instructional ideas had been severally formulated to provide personally satisfying rational systems of explanation?

The social construction of meaning

One obvious question which the personal rational position found difficult to answer was why particular constructs are so widespread - at least within one culture or one language group. The last seminar heard about quite different ideas about energy which were widely held by German, British and Philipino students (Duit, and Solomon)

Children are great social communicators long before they learn about scientific ways of constructing theories. Social interactions are based on empathy rather than consistency because they depend on the shared understanding of meaning. Not just children but all of us strive hard to fit into the general scheme of what is being discussed, and we also rely very strongly on messages of recognition, understanding and

support which come back to us from others when we speak about our experiences. Back in 1934 Mead had written that social interactions are responsible for the appearance of new objects in the field of our experiences and indeed that "objects of common sense" can only exist through this social communication. Both he and Schutz (1973) wrote of the "interchangeability of perspectives" with others who have a social relationship with us. If the construction of the meaning of an experience takes place within a group of friends it is small wonder that students' notions are found to be common to many. If the art of changing perspectives is a prized empathic skill in social circumstances it also explains why students' explanations can be so inconsistently applied without causing them any apparent cognitive discomfort. It was this line of argument which I presented at the last symposium to explain the curious data recorded in group discussions on the topic of energy. Since then the work of the CLIS (Children's Learning In Science) project has set out to document classroom interactions between students in order to monitor the changing conceptions of British school pupils as they learn science in the teaching laboratory.

The linguistic and cultural aspects of the social construction of knowledge are a field of study in themselves. Some idea of the daunting scope of this field is to be found in a recent review article Social Influences on the Construction of Pupils' Understanding of Science

Solomon 1987. It is altogether too large a subject to be considered in this article.

Personal styles of verbal expression Electricity.

To these three perspectives - personal rationality, experiential actions, and social mediation - some more need to be added. What I have in mind are individual in character but not related to rationality of construction as much as to other personal traits. Some of this may relate to the kind of work on cognitive style carried on by Pascual-Leone et al (1978), Case and Globerson (1974) and diSessa (1984) although I would be chary of using such sharp notions as "field dependency", or "problem-solving strategy" in too prominent a fashion. Instead I would explain personal style in a more general and commonplace way - as the choice of verbal, mathematical, or visual modelling which seems appropriate to any individual student.

This area is so fluid and idiosyncratic that it is hard and perhaps misleading even to try to discuss it in any theoretical way. Instead I want just to describe some data obtained by the British STIR (Science Teachers In Research) group in the field of electricity. These are to be found set out in greater detail in Solomon et al (1986) and Solomon et al (1987).

The study of pupils' view of electricity was carried out among Grade 6 students who had not yet been taught a formal school course about electricity and Grade 8 students who had. It took place in four different schools by means of a variety of tests. In the first place the students were asked to give a piece of free writing about electricity, then to use simile to describe what they thought electricity was like, and then to put a ring around the places in a set of four drawings where they thought that the electricity might be located. In a follow up exploration of the responses to these sections a series of group interviews were carried out.

In the earlier paper (1986) the results of a network analysis of the free writing showed the similarity of the views and beliefs about electricity given by the two groups of children. We assumed from this that these were socially derived notions which had proved either resistant to or emotionally more salient than the teaching given at school. The main areas used in the analysis were USE, DANGER, SUPPLY and PHYSICS (this latter to be taken very loosely as being an early attempt at conceptual formulation). We were intrigued at the large category of grade 6 responses in the DANGER category, which had diminished significantly two years later. The repetition of phrases used was striking and suggestive of social maxims ("You can't mix electricity and water", and "Electricity is very useful to us")

In the simile section of the paper we observed a significant change over the two years only in agreement with proposition that electricity was like a river ... "because it flows". Was this the result of school teaching or access to new vocabulary and its latent analogies?

After this preliminary analysis had shown both the background of socially acquired knowledge and the very slight conceptual advance produced over the two years, we began a second tier of analysis to answer the following questions:

What might have caused the fear of electricity which seemed to underlie the DANGER statements?

Was there any structural difference in the way the two year groups expressed themselves in their writing?

Was the correct use of simile an equal problem to both year groups?

We sought an answer to the first question partly by group interviews of "fearing" and "non-fearing" students (as defined by the number of DANGER statements made), and partly by internal evidence within the questionnaire. We found that having had an electric shock was not a significant factor in being fearful, but that not having full parental licence to use electrical appliances unaided was. We also found that

these fearing children were much more likely than the others to place a ring around the plug of a disconnected table light as a place where there was electricity.

We deduced from this that familiarity with the use of electricity had moved the locus of electricity from touching the plug to engaging it in the socket. Here were indications of a change in conceptual understanding very nicely related to motor learning.

Examining the sentences from a syntactical point of view proved interesting. We employed the categories -

- (A) "I", "we", or People as the subject of the sentence.
- (B) "Electricity" is the subject of a subjective judgement.
- (C) "Electricity" is the subject of a factual sentence.
- (D) "Electricity" is the subject of an attempted definition using the verb to be.
- (E) "Electricity" is the subject of an operational definition using a verb other than "is".

This analysis showed a regular age progression. It was similar to one found by Kempa and Hodgson (1976) in sentences written about the nature of acids, in which these authors had found an age progression which did not seem to be related to high and low scorers in an IQ test.

The nearest we had come to setting an intelligence test was

the use of simile, and this was itself fortuitous. We were surprised how many mistakes in the operation of a simile were made. This skill at finding a quality through which to compare two objects also showed significant development from grade 6 to the grade 8. However it was interesting to find that, within any one year group, there was no significant correlation between ability in the use of a simile and the hierarchy of sentence construction.

This conclusion was intriguing and difficult to categorise. On the one hand progress in written descriptions of electricity might have been the result of social influences - the way in which peers or family habitually speak affecting how the child's sentences were constructed. On the other hand it could have been a simple expression of different verbal style, unrelated to analytical prowess. The work on electricity was thus completed without giving any way to distinguish between these two alternatives.

Personal styles of non-verbal expressions Light

A small study of Grade 8 students beginning their first course on Optics was carried out in one British school. Before the course began the students were asked to discuss what they knew about light and then they were given coloured pencils and asked to draw a picture of a sunset putting in all they could about light. In their first lesson the same students were given a ray box and a lens which enabled them

to trace diverging, converging and parallel beams of light across a piece of paper. They were also asked to obtain shadows with each kind of beam. There was no overt instruction on shadows but the students were asked to observe the nature of the shadows produced. Shortly afterwards they were asked to draw diagrams to show why a person's shadow was different in the morning when the sun was high in the sky, and in the evening when it was lower down. Then they were asked, in the next lesson, to write down what a shadow was. These three sets of data were then compared.

The collection of coloured pictures ranged from a lurid orange ball cut in half by the horizon, to more complicated sea or landscapes in which several other objects were sketched. Since the students had been asked, at least twice, to show all they could about light in their pictures, these were simply categorised into ones where light effects were shown - lighter and darker shading on the sides of objects or clouds, shadows or paths of light across the sea (a corny but common theme!) - and others which showed no light effects at all apart from uniform sunset colours.

The diagrams of shadows were surprising. Some used rays or the position of the sun to locate the shadow; others did not, and even drew the shadow as a black shape completely separated from the person. In the written explanation it was again possible to see two main categories of response, those

who spoke of a shadow as where the sun's light was blocked out, and those who simply referred to a shadow as an image, shape or reflection of a person without any causal reference to the sun or its light (Solomon 1986). A comparison between these two pieces of work on shadows showed a high and significant association - $Q=0.81 \pm 0.14$ ($n=36$). This seemed to show that the analytical approach could display itself in both words and simple diagrams.

However when the coloured pictures were examined no significant association of any kind could be found. These were obviously not diagrams and although it was quite possible to pick out the ones where light and colour effects of the setting sun were faithfully reproduced, they were as often given by students who thought non-causally about shadows, as by those who later carefully drew in rays of light in order to define the shape and size of shadows. We might perhaps conclude from this that those who are entranced by coloured effects and remember them well, do not necessarily care to think in an explanatory way about them. It might be typified perhaps by Leonardo da Vinci's minute exploration of the blueness of distant vistas and the colours within shadows, as compared with Isaac Newton's preoccupation with using his particle theory of light to explain refraction and dispersion.

So, four years on from the First International Symposium, it seems that the task of understanding school students' notions may be even more formidable than we had then supposed. Personal rational constructivism would have been a relatively easy item to have absorbed into science education. Without it we are thrown back on to socially mediated meanings. This not only presents more difficulty for understanding the fluid notions of students, it also gives us the harder job of introducing them to a new way of thinking which is more rational and more context-independent than they have ever encountered before. Aikenhead (1986) has documented the gross misunderstandings that even Grade 11 students have about the nature of scientific knowledge and has claimed that this, more than any other, is the most crucial and basic task for science education.

There is one more reflexion on personal cognitive style that might well link up with the previous point. It seems likely that if a topic in science education has either emotional or evaluative overtones it will also engage individual students to a different extent in accord with their different personal reactions. We have only to reflect on the enormous difficulties encountered by Kohlberg in his attempts to categorise students' responses to moral problems to see yet another faculty that does not correspond to the usual norms of cognitive development. This would then make another dimension to personal cognitive style which might become

very important when, for example, environmental or nuclear issues were being considered during science lessons.

The public understanding of science in these crucial areas is of special importance to our nations. Its difficulty is confounded by a lack of understanding about the rational but incomplete nature of scientific knowledge, as well as being coloured by a variety of different personal perceptions. Like other aspects of learning it is mediated through social interactions. Whatever way we look at it the science education of our future citizens is a superbly challenging task!

REFERENCES

- Aikenhead, G.(1986) Student beliefs about Science-technology-society. J.Res. Sci Teaching (in press)
- Case, R. and Globerson, T.(1974) Field independence and central computing space. Child Development 40 p772-778.
- Chmapayne,A and Klopfer, L. (1980) Cognitive research and the design of science instruction. Ed Psychol 17: p31-53.
- DiSessa,A. and Globerson, T.(1984) Investigating the effect

of age and cognitive style on children's intuitions of motion National Logo Conference. Cambridge Mass.

Helm, H. and Gilbert, J. (1985) Thought experiments and physics education. Phys Ed 20(3) p124-133.

Hewson, P (1981) A conceptual approach to learning science Eur J Sci Ed 3(4) p 383-396.

Kelly, G. (1955) The Psychology of personal constructs W.W.Norton

Kempa, R and Hodgson, G (1976) Levels of concept acquisition and concept maturity. British J Ed Psych 46 p253-260

Mead, G.H.(1934) Mind Self and Society Univ of Chicago.

Osborne, R. and Bell, B. (1983) Science teaching and children's view of the world. Eur J Sci Educ 5(1) P1-14.

Pascual-Leone, J. Goodman, D. Ammon, P. and Subelman, I. (1978) Piagetian theory and neo-Piagetian analysis. In Knowledge and Education Ed McCarthy, Gallagher and Easley. Plenum.

Polanyi, M. (1958) Personal Knowledge RKP.

Pope, M (1982) Personal construction of formal knowledge. Interchange 13 (4) p3-15.

Schutz, A and Luckmann, T (1973) Structures of the Life World Heinemann.

Solomon, J. Black, P. Oldham, V and Stuart, H. (1986) The Pupil's view of electricity Eur J Sci Ed 7 p281-294.

Solomon, J (1986) Children's Explanations Oxford Review of Educ 12(1) 41-51

Solomon, J. Black, P. and Stuart, H. (1987) The pupil's view of electricity revisited: social development or cognitive growth? Eur J Sci Ed 9(1) 13-22

Solomon, J. (1987) Social influences on the construction of pupils' understanding of science. Studies in Science Education (14) p63-82

Strike K, and Posner G (1982) Conceptual change and science teaching. Science Education 4(3) p 231-240

Viennot, L. (1979) Spontaneous learning in elementary dynamics. Eur J Sci Ed 1(2) p205-221

ACQUISITION OF CONSERVATION OF MATTER

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According to Piaget, quantitative conservation is possible at the concrete operational stage when children possess reversible logical operations (compensation, negation, identity or additivity). In our previous research (Stavy and Stachel 1985.), as in many others (Lovell and Ogilvie, 1961-62; Uzigris, 1964), it was found that, as opposed to what is expected according to Piaget's stage theory, children can conserve weight in some tasks but not in others.

Lovell and Ogilvie explain this horizontal decalage by saying that although logical thinking is an essential condition for weight conservation, it is not enough. Experience in the physical world has a much larger role than expected, therefore conservation does not develop in an all or none process but is developed gradually. Inhelder Sinclair and Bovet (1974) claim that during the process of constructing their knowledge, children come across much resistance from their surrounding which is the cause for horizontal decalage.

Another approach to conservation of weight problems will be presented in this paper. Misconservation will be presented and interpreted in terms of specific alternative conceptual framework. Thus, the development of conservation of weight in different transformations of matter will be described and discussed. Educational implications will also be discussed.

Methodology

The Sample

The sample included students of middle class population from the first grade (ages 6-7) until the ninth grade (ages 14-15). Each age group comprised 20-25 students. Each student was interviewed independently while being showed the materials and the processes. Each student was asked only two of the tasks.

In the seventh grade students in Israel study the chapter "The Structure of Matter" (Orpaz, Ben-Zvi) which deals with the particulate theory of matter, in the eighth grade they study the chapter "From Elements to Compounds" (Arazi, Sivan) which deals with elements and compounds, the periodic table of the elements and electrical phenomena of matter.

The Tasks

a. Melting task:

Candles: Two identical candles were given to the child who was asked to judge the equality of weight. One of the candles was then melted and the child was asked about the equality of weight and about the reversibility of the process.

Ice: The child was presented with two identical test tubes. Each contained an equal amount of ice. The child was asked to judge the equality of weight. The ice in one of the test tubes was melted and the child was asked about the equality of weight and about the reversibility of process.

b. Evaporation tasks:

1. **Acetone:** The subject was presented with two closed identical test tubes. Each contained an equal amount of acetone (one drop). The subject was asked to judge the equality of weight. The acetone in one of the test tubes was heated until it completely evaporated. The student was asked about the equality of weight and about the reversibility of the process.

2. **Iodine:** The subject was presented with two closed identical test tubes, each containing an iodine crystal (two equally sized crystals). The subject was asked to judge the equality of weight. The iodine in one of the test tubes was heated and turned completely into purple gas which filled the whole volume of the test tube. The subject was asked about the equality of weight and about the reversibility of the process.

c. Dissolving of sugar task:

The subject was presented with two identical cups containing equal amounts of water and with two identical tea spoons containing equal amounts of sugar. The child was asked to judge the equality of weight of the two systems. One tea spoon of sugar was put next to one of the cups and the second was dissolved in the water in the second cup. The child was asked about the equality of weight of the two systems.

d. Expansion of Water task:

The subject was presented with two small vials each of which was filled to the top. A rubber stopper with a hole in it was placed in the vial's opening and a thin glass tube was inserted into the hole of the stopper, so that it slightly entered the vial. One of the vial was heated and the water rose into the tube. The child was asked about the equality of weight of the two vials.

Results

A. Conservation of Weight in different types of transformations of matter.

The classic task concerning weight conservations developed by Piaget, is that of the plasticine ball deformation. Six to seven year old children succeed in this task using explanations of: identity (it is the same plasticine); reversibility (the ball can be changed back); compensation (there are more pieces but they are smaller); additivity (nothing was added or subtracted). This means that children at this age have the logical ability to deal with certain weight conservation tasks.

When children are presented with weight conservation tasks which involve change of state their responses are different. As opposed to the linear curve of development in the success of the plasticine conservation task (with a rise from 20% to 80% in the second grade), the development

curve with regard to the success of the melting of ice task is not linear, but rather is an S-shaped curve with a sharp rise at the third grade (5% - 45%), a shoulder and a second rise at the fifth grade (55% - 75%). The evaporation of acetone task shows a linear rise from 0% - 80% from fourth to ninth grade. It seems, therefore, that the capacity to conserve weight depends on the nature of the transformation. It is first expressed in the case of the simple change of translocation, then in the process of change of state from solid to liquid and finally in the process of change from liquid to gas. (see fig. 1).

Insert Fig. 1.

The majority of students who did not answer correctly the melting of ice task believed that ice is heavier than water or that water has no weight. Few of the younger ones believed that water is heavier than ice. With regard to the evaporation of acetone task the younger students in the sample tended to believe that gas has no weight and the older ones that liquid is heavier than gas.

The development of conservation of weight in the processes of dissolving sugar in water and expansion of water by heat are very similar to the development of conservation in the melting of ice task (Fig.2)

Insert Fig. 2

The younger students who did not respond correctly to the sugar water task believed that the sugar water is heavier than the sum of the weights of sugar and water because "sugar is heavy and it makes the water heavier". The older ones tended to believe that the sugar water is lighter than the sum of the weights of sugar and water because

"the sugar becomes smaller and smaller until it disappears."

In the expansion of water task the majority of students thought that the hot water is heavier because its volume is expanded. But few of the older student (grades eight and nine) thought that "cold water is always heavier" and some even explained that the density of cold water is larger.

It seems that children construct a set of intuitive rules or propositions regarding the correlation between the weight of matter and its state. The rules found in the case of evaporation were : I - gas has no weight; II - gas always weighs less than liquid; III - the weight of gas is equal to the weight of the liquid from which it was made. The following rules were found in the case of melting:

I - liquid weighs more than solids; II - liquids has no weight; III - liquids weigh less than the solids; IV - the weight of a liquid is equal to that of the solid from which it was formed.

Similar rules were found regarding dissolving of sugar in water (which might be perceived by students as melting): I - sugar water is heavier than the total weight of sugar and water; II - the dissolved sugar has no weight; III - the weight of the sugar water is smaller than the total weight of sugar and water; IV - the weight of the sugar water is equal to the sum of the weights of the sugar and water.

All these rules stem from intuitive feeling that children have regarding "lightness" and "heavyness" of matter (or groups of materials) which is an intensive "quantity" or property. The child refers to the intensive quantity instead of the extensive quantity, weight, about which he was asked. Can it be assumed that the child does not properly understand the meaning of the term weight and thinks that weight refers to the specific weight of the material? This is almost definitely not the case. It is

clear that from a very young age children understand what the weight or heaviness of an object is, and know that a large body of a certain material is heavier than a smaller body of the same material. A reversed behavior was observed by Piaget and Inhelder (1974) and Megged (1978) who studied the development of children's concept of density. (see Fig. 3).

Insert Fig. 3

Children were asked about floating or density - an intensive property of matter, and they responded as if they had been asked about weight which is an extensive property of matter. For example, children were presented with two pieces of iron, one was a large and heavy cube and the other was a pin. The child was asked to predict whether the object would sink or float. Children under the age of twelve thought the pin would float since it was light and "light things float". It is possible to explain this difference between the responses as follows. The major change in the case of evaporation is change in the state of matter which is expressed as a change in density. While in the case of floating the main change is in the size or weight of the piece of matter. It is possible that children's cognitive system is affected by the changing dimension, such as density, and regards it as the significant dimension in the problem and looks for ties which are appropriate to the situation. And indeed, some of the rules presented here are correct in other situations. There is no doubt that studying chemistry in the seventh and eighth grades might reinforce these rules (for instance "gas weighs less than liquid" or "liquid

weighs less than a solid"). Apparently the term "weight" is connected in the child's cognitive system with "specific weight" and "absolute weight" (and probably also with other "weight" aspects such as swings, balance scales, free fall, etc.) These terms are not defined well enough and as long as they are not fully differentiated the child can use them according to the specific characteristics of the situation.

B. The effect of context on weight conservation.

Children's responses to tasks which are essentially identical such as evaporation of acetone and evaporation (or sublimation) of iodine were compared. The iodine, as opposed to the acetone has color and can be seen in its gaseous state. As can be seen from Fig.4. many more students in the fourth to seventh grade conserved the weight of iodine, than they did with regards to acetone.

Insert Fig.4

Children in this age group who conserved the weight of iodine and not that of acetone were clearly relating to the fact that they could see the material. They explained their answers with explanations similar to those given for the weight conservation of the clay ball task (Piaget): "the crystal becomes crumbs so it is exactly the same thing" or "the same thing that was in the crystal is in the test tube" or "since the crystal dissolved". From the seventh grade on, children begin to regard weight conservation of iodine in the same fashion that they regard acetone and their explanations are similar, "only the state of matter was changed" or "nothing was added or subtracted". A few children referred to particles and said, "the particles only got farther apart". Explanations to

incorrect answers among this age group were also similar "gas is weightless" or "gas always weighs less than a solid".

Apparently specific perceptual input from the task affects children's judgements. Beginning in the seventh grade the effect of perceptual input disappears and the percentage of success in the two different tasks become parallel. One can assume that at that age all tasks of change of state, are represented in the same way and this may symbolize the beginning of formal conservation.

However, two melting tasks, the melting of ice and the melting of candle wax show closer developmental curves (Fig.5).

Insert Fig. 5

And the developmental curves of success in the sugar water task, expansion of water task and evaporation of iodine task are similar to them. All these tasks are perceptually similar: they are concrete and involve change in the volume or organization of matter. Apparently, students relate to all of them in a similar way.

C. Conservation of weight and Reversibility

The understanding of reversibility was not found to be prerequisite to the capability of weight conservation. There were cases in which children conserved weight without understanding the reversibility of the process (melted candle, iodine sublimation) and (rare) cases in which the children understood the reversibility of the process but did not conserve weight.

It turns out that the two developmental curves of the success in the reversibility tasks - (the evaporation of acetone and sublimation of iodine) - are very similar (see figure 6). The curves are linear and have a sharp rise around age twelve-the seventh grade (at age fourteen a

fall appears which is different for each of the tasks apparently because of over sophistication and attention to technical details regarding the reversibility of the process). These facts suggest that children represent the reversibility tasks related to the process of change of state from liquid to gas in the same way and are not affected by perceptual elements of the task. It is possible that the understanding of the reversibility of the process which emerges at the age of 12 is a result of school learning in addition to the development of formal thinking. (The structure of matter, which deals with changes in states of matter, is taught in the seventh grade). The reversibility curve is almost identical to that of the conservation of weight in the acetone evaporation task, which is the most difficult of the task presented here. It is therefore possible that there is

Insert Fig. 6

some correlation between understanding of reversibility and the capability to conserve weight in cases in which there are no supporting perceptual elements, or during ages when these elements do not serve as supporting entities. The developmental curve of success in the reversibility of melting a candle also develops gradually from kindergarden until age fourteen. (see fig. 7). This curve proceeds that of reversibility of evaporation by approximately four years.

In the case of melting ice majority of children between the ages of six and fourteen understand the reversibility of the process although many of them do not conserve weight during this process. It is possible that children of these ages do not have a general conception of the

reversibility of the melting process but judge each case specifically.

Insert Fig. 7

Discussion

Piaget relates the capability of conservation at the stage of concrete operations to the development of logical operations. As it turns out these logical operations do not suffice to enable dealing with certain conservation tasks. Specific knowledge about the change, and about the properties of the quantity in question and about the boundaries within which it is conserved is necessary. For instance, the mass and weight of matter are conserved during a change of state though its volume is not. From a logical point of view the same logical claims of reversibility, identity and additivity can be made regarding mass weight and volume. In addition, in many cases of chemical changes considerations of reversibility or identity cannot be made (there are irreversible processes and the identity of matter is not conserved during chemical processes); none the less, matter is conserved.

Many scientists regard the laws of conservation as empirical laws which state that for a given system of objects there exist measurable quantities whose total amount does not change. The laws determine the conditions in which each quantity is conserved.

In his book "The Various Language", A. Arons (1977) wrote: "The law of conservation of matter cannot be proved to be true by some system of deductive reasoning from more fundamental principles...it is induced from a limited amount of empirical data. We have, however, over a period of 200 years come to hold a very deep belief of its validity".

Obviously children do not have directed empirical experience which would lead them to the laws of conservation. Apparently the logical operations which develop with the development of concrete operational thought, are those which

enable children at ages six and seven to solve certain problems of conservation. The question arises: Why don't children use these logical operations in order to solve other conservation problems?

In this paper we have demonstrated that children solve certain conservation problems without being able to solve others. We have also shown that in addition to the logical operations related to conservation, children have much factual knowledge about matter which changes with age and possibly as a result of formal schooling. We will try now to answer the question posed above.

As a result of an internal representation of a problem a person (or a child) is faced with, many different bits of his knowledge are activated or aroused. These bits of knowledge compete with one another over the problem solving mechanism in such a way that the strongest knowledge relevant to the problem, at a given moment, overcomes all other bits of knowledge. The strongest knowledge relevant to the problem will be that which will affect the person in his solution of the problem. So even if the appropriate knowledge exists in the cognitive system it will not always be expressed in solving the problem. This explanation enables us to understand the horizontal decalage found in this research and others regarding weight conservation problems, and the non-linear development of the success in these tasks. For instance, half of the children above the age of seven conserved weight in the melted candle task using logical additivity justifications, the other half used their knowledge that a solid candle was heavier, whereas they all responded correctly to the weight conservation task with the plasticine. In the case of the plasticine apparently no competitive knowledge is activated which explains the high degree of success. In the case of the candle two sets of knowledge of equal strength are probably used.

Among the older children (ages eight to nine) the knowledge that the solid candle is heavier strengthens as the result of experience in the physical world and successful use of this knowledge in solving other types of problems (solids

usually have higher specific weights than the corresponding liquids), so the percentage of success drops and then rises again in the sixth and seventh grades (ages eleven and twelve) when the knowledge that solids are heavier is channeled to relevant problems and no longer competes with the logical operations relevant to conservation. This process of finding the boundaries within which one's knowledge is applicable may lead one to identify (even unconsciously) a problem and relate to it according to its type or category (even if the response is incorrect). In such a case the person's response will not be affected by irrelevant perceptual information and the solution will deal with the type and essence of the problem - that is a more formal or abstract response. In addition, the different bits of knowledge may get temporary support from immediate perceptual inputs of the task verbal, visual or that which is related to the dynamic aspect of the task. In summary the different types of knowledge that exist in the cognitive system of the child regarding certain physical entities compete with one another and with the correct knowledge which also may exist in the cognitive system. This is a dynamic competition between the different knowledge systems in which the strongest knowledge prevails. In our case the children have the operative knowledge necessary to solve the weight conservation problems but instead they use irrelevant knowledge which, at certain ages or situations, is quite strong.

This reciprocal game between the different knowledge systems is a progressing process through which the child gradually learns the boundaries within which his knowledge is applicable. It is possible that the expansion of knowledge starts with instances in which positive reinforcement exists for correct knowledge from immediate perceptual input and from those transferred by analogy to similar cases in which it does not.

Applications for science instruction

We will divide the discussion on instructive applications into two parts: The first part will deal with specific

applications regarding education in the subject of "The states of matter". The second part will be more encompassing and will deal with science teaching in general.

a. Specific applications

The law of conservation of matter was a breakthrough to the particulate theory of matter and modern chemistry and one can assume that it is basic knowledge that should be used to develop the particulate theory and modern chemistry among students also. Results of this research show that only 50% of the seventh grade students understand the conservation of matter in the process of evaporation; The particulate theory of matter is taught on the basis of this faulty knowledge. This may be the reason that no students in the seventh grade and only 15% in the eighth and ninth grades used the terms from the particulate theory in their explanations. In light of these results we recommend teaching the conservation of weight, at least regarding changes of states of matter, before beginning to deal with the particulate theory and with chemistry and while teaching these subjects to emphasize, and expand the conception about conservation of matter regarding chemical processes also.

Instruction of conservation of weight should be done in the following sequence: (1) conservation in translocation - crumbling a lump of solid into powder, (2) conservation during melting, dissolving and in changes of volume (of solids and liquids) during heating (or cooling) (3) changes of solids or liquids to gas (one should start with materials which have clear perceptual properties in the gaseous state), and changes of volume of gas (heating or compressing) (4) chemical reactions which do not involve evolution or absorption of gases, (5) chemical reactions in which gas is evolved or absorbed.

In all these transformations the reversibility of process must be regarded as must the conservation of qualitative properties both in processes in which the identity of the matter is conserved and they are reversible and in those that

the identity of the matter is not conserved, nor are they reversible.

B. Pedagogic applications

When a new phenomenon, term, law or theory is being taught one should try to begin with an example for which there is maximal perceptual reinforcement for correct intuitive knowledge. For instance, in weight conservation in the process of evaporation one should start (at an appropriate age) with colored matter (such as iodine) in order to reinforce the intuitive knowledge that exists, that weight is conserved in this case. Only then should one proceed by analogy to cases in which the perceptual reinforcements are diminished (for instance colorless matter with smell and then colorless matter with no smell). When instructing science it is common to present ideas or new phenomena with the most characteristic examples instead of those with the most perceptual elements. For instance in the subject of gases examples of oxygen, nitrogen, carbon dioxide, ammonia, etc. are given but not iodine, bromine, chlorine or nitrogen oxide which are colored. The opposite is also true - in cases in which the common typical exemplars have strong perceptual reinforcements other examples are not usually given. For instance, while teaching the term liquid the common examples of water, oil, etc. are given. These have strong perceptual elements which help classifying them as liquids. If this is not augmented with examples of viscous liquids or powders nothing is added to the existing intuitive knowledge. This type of instruction should be tried and tested. It demands knowledge about the intuitive ideas that children have at different ages about phenomena, terms or ideas related to science.

2. Since we saw that the success of solving a problem depends on the dynamic competition between the different bits of knowledge in which the stronger knowledge prevails, it is clear that the child should be assisted in strengthening the correct bits of knowledge in his cognitive system, and should be helped

to find the boundaries within which this knowledge can be applied. This can be done by giving the students chances to use their knowledge in solving different problems and to allow them to propose hypotheses and examine them in light of the physical reality.

3. We have seen that during the process of acquiring conservation of weight skills the child goes through a stage in which he reacts and responds to all evaporation problems in the same fashion (even if incorrectly so) and does not relate to any irrelevant elements. This attitude enables correct responses to this type of question at a later stage. From this we see that the relation to the type and the essence of a problem and relating it to the characteristic category of problems can be an important stage towards the capability of solving such problems and towards acquiring the general knowledge relevant to them.

Bibliography

- Arazi, J., Sivan, I. (Undated). From Elements to Compounds, TL (In Hebrew).
- Arons, A., The Various Language, New York: Oxford University Press, 1977, p. 39.
- Inhelder, B., Sinclair, H. & Bovet, M., Learning and the Development of Cognition. Cambridge: Harvard University Press, 1974.
- Lovell, K., & Ogilvie, E., A Study of the Conservation of Weight in the Junior School Child. British J. Educational Psychology, 1961-1962, 31, 138-144.
- Megged, C., The Development of the Concept of Density in children from ages 6-16. M A Thesis Tel Aviv University, 1978.
- Orpaz, N., Ben-Zvi, R., undated, The Structure of Matter, TL (In Hebrew).
- Piaget, J. & Inhelder, B. The Child's Construction of Quantity: London: Routledge and Kegan Paul, 1974. (Original, 1941).

Stavy, R., and Stachel, D. Children's Conception of Changes in the State of Matter: From Solid to Liquid. Archives de Psychologie, 1985, 53, 331-344.

Uzigris, I. C., Situational Generality of Conservation. Child Development, 1964, 35, 831-841.

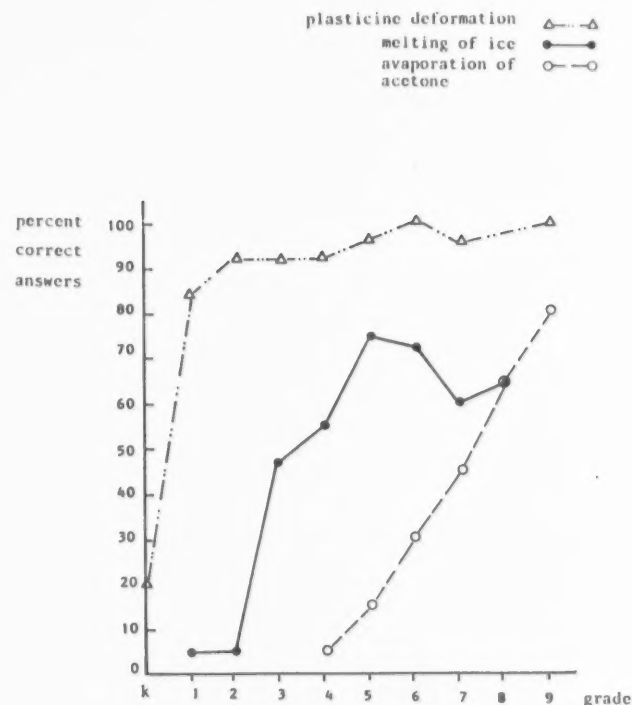


Fig 1: percent correct answers across age for different conservation of weight tasks.

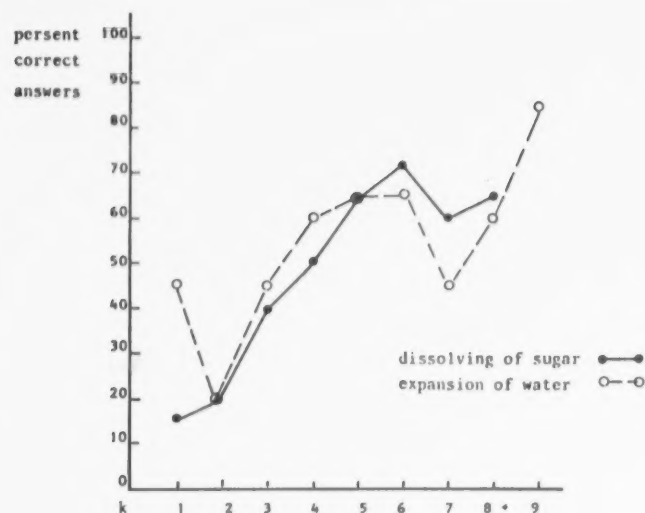


Fig 2: Percent correct answers across age for conservation of weight in dissolving of sugar and expansion of water tasks

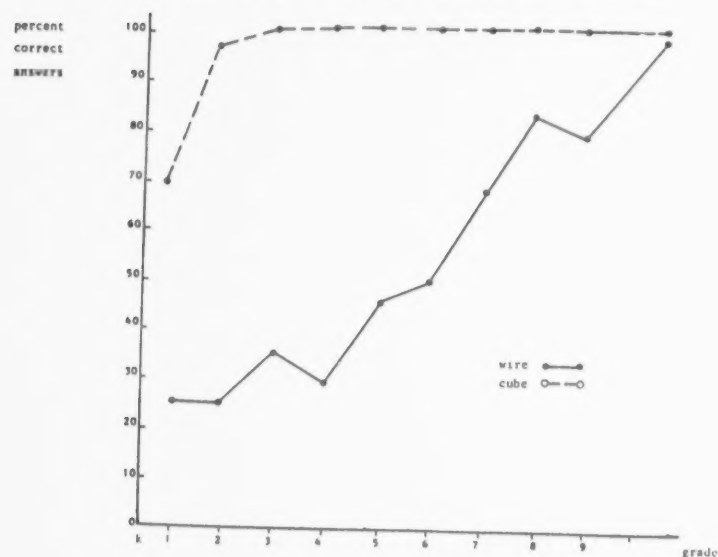


Fig 3: Percent correct predictions across age for floating and sinking of iron cube and iron wire
From Hegged (1974)

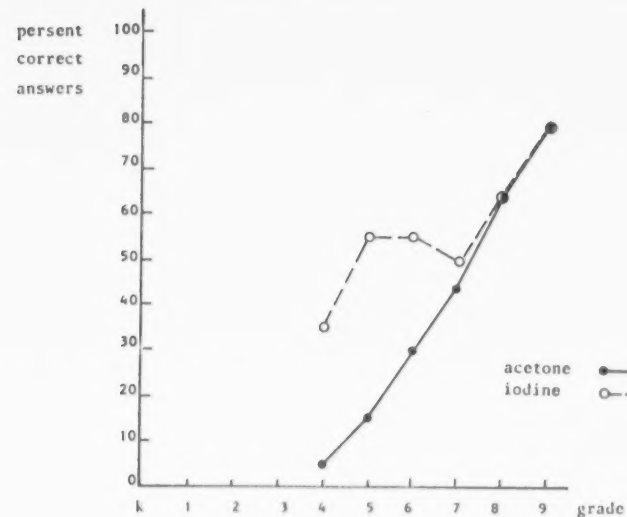


Fig 4: Percent correct answers across age for conservation of weight in different evaporation tasks.

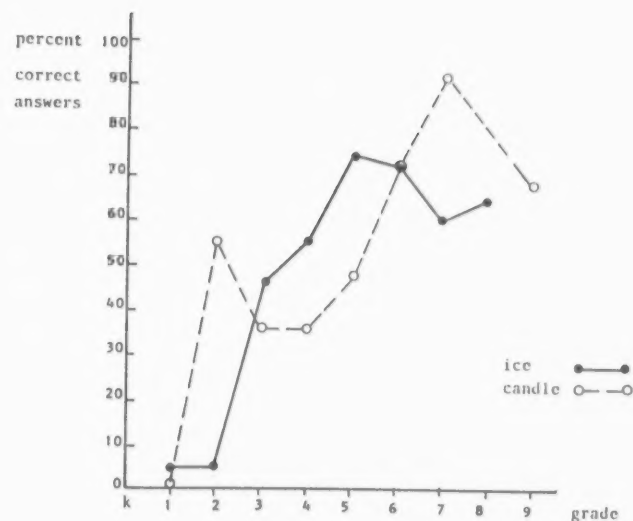


Fig 5: Percent correct answers across age for conservation of weight in different melting tasks.

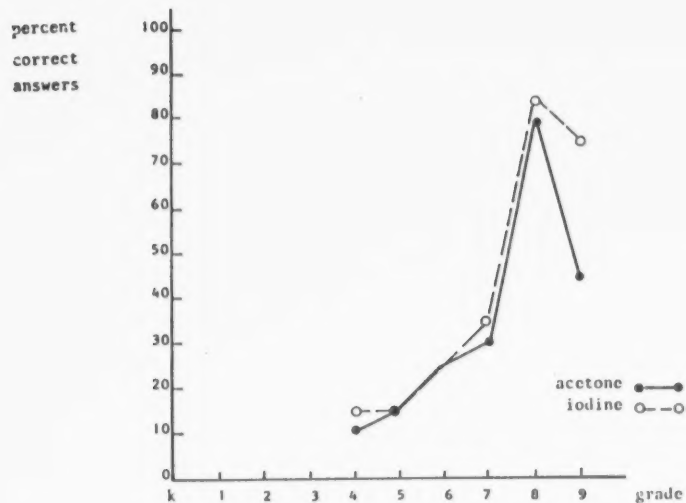


Fig 6: Percent correct answers across age for reversibility of evaporation tasks.

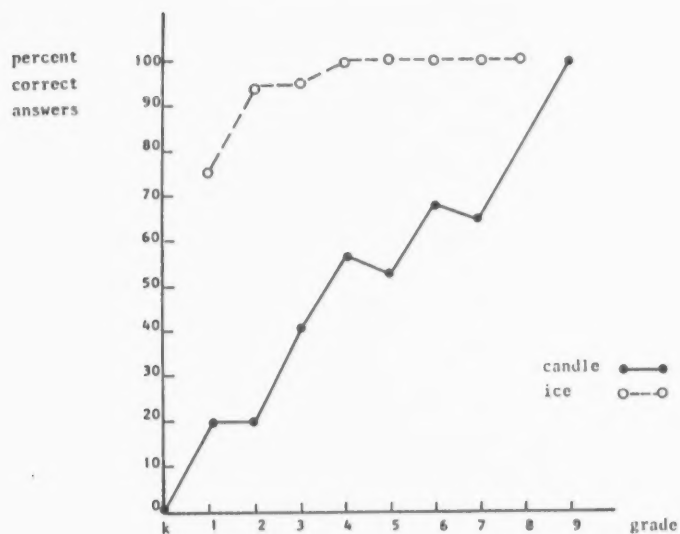


Fig 7: Percent correct answers across age for reversibility of melting tasks.

USING THE PERSONAL INTERVIEW TO DETERMINE STUDENT
MISUNDERSTANDINGS IN SCIENCE AND SOME SUGGESTIONS
FOR ALLEVIATING THOSE MISUNDERSTANDINGS

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Students coming into a learning environment bring their own conceptions of the world. These conceptions are not necessarily those of scientists that are accepted as "correct" by curriculum writers and teachers. Despite what teachers think about science concepts, many students maintain their early and erroneous concepts of the world for several years, and even into adulthood.

This paper will focus on the following questions:

1. What are students' misunderstandings of some common science concepts?
2. What is the pattern in students' misunderstandings of concepts at different educational levels?
3. What instructional practices can be used to bring about a conceptional change in students?

I. To address the first question, we would report on two studies [11,12]. In both, a group of randomly selected elementary school children was interviewed on such common science concepts as living vs. non-living and weather.

IA. The subjects for this study were selected from four different classes — two second grades and two fifth grades — in two different schools. One second grade and one fifth grade used textbooks as a basis for instruction. The other two classes used Elementary Science Study (ESS) and other hands-on activities as their science programs. Fifteen students were randomly selected from each of the four classes.

Interviews began with a general question—for example, "What is wind?" The next questions depended on the answer that the child had given. Subsequent questions were also tailored to the child's responses and were designed to probe the child's understanding of the topic. As the following sample interview with an 11 year old shows, continued questioning sometimes uncovered misconceptions beneath what had looked like a solid grasp of a concept:

Interviewer: What is rain?

Child: It's water that falls out of a cloud when the clouds evaporate.

Interviewer: What do you mean clouds evaporate?

Child: That means water goes up in the air and then it makes clouds and then, when it gets too heavy up there, then the water comes and they call it rain.

Interviewer: Does the water stay in the sky?

Child: Yes, and then it comes down when it rains. It gets too heavy.

Interviewer: Why does it get too heavy?

Child: 'Cause there's too much water up there.

Interviewer: Why does it rain?

Child: 'Cause the water gets too heavy and then it comes down.

Interviewer: Why doesn't the whole thing come down?

Child: Well, 'cause it comes down at little times like a salt shaker when you turn it upside down. It doesn't all come down at once 'cause there's little holes and it just comes out.

Interviewer: What are the little holes in the sky?

Child: Ummm, holes in the clouds, letting the water out.

After the interview, a child's responses were placed into one of five developmental categories based on the work of Piaget and on Fuson's later discussions of Piaget [7, 4]. These stages, called feelings of participating, animism, artificialism, finalism, and the true causality, are briefly described below. Each description includes a student response illustrating that particular stage:

1. Feelings of participation. The child thinks he or she participates in the actions of nature. Sometimes these feelings are accompanied by a belief in magic.

Interviewer: What makes the clouds move along?

Ten year old: It's when you walk.

2. Animism. The child attributes life and consciousness to inanimate objects.

Interviewer: What is rain?

Seven year old: Clouds think it's too hot, and one day they start sweating. I guess they start sweating and then the sweat falls on us.

3. Artificialism. The child thinks that things happen for the good of human beings and other living things.

Interviewer: Why does it rain?

Eleven year old: To give us moisture and the better our crops grow.

4. Finalism. The child thinks that there is an explanation for everything. (The explanation is not scientifically accurate, and it does not fall within the categories already mentioned). We identified two major subgroups within this category.

- 4a. Religious finalism. In these explanations, the child refers to supernatural causes such as God and angels.

Interviewer: What is thunder?

Five year old: Thunder is when God becomes mad at all of the angels.

Interviewer: What is lightning?

Five year old: The noise that the angels make when they are crying after God had yelled at them, like Mom does to me.

Interviewer: What is rain?

Five year old: The tears of God and the angels crying after they have made friends again.

- 4b. Nonreligious finalism. In these explanations the child makes no reference to the supernatural.

Interviewer: What is snow?

Seven year old: There are white mountains where white bears live and they cut out snowflakes and they would spread them all over.

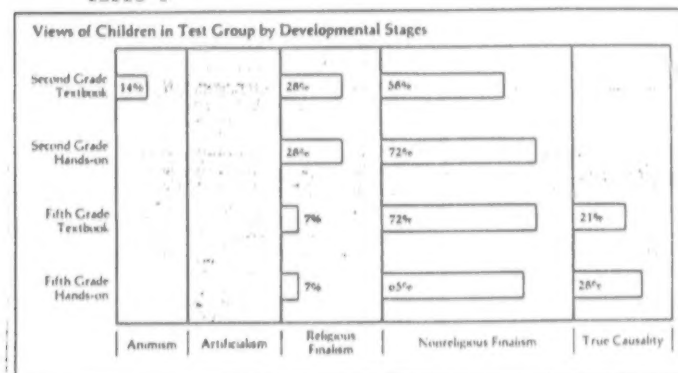
5. True causality. The child gives an accurate explanation for the physical phenomenon.

Interviewer: Why does it rain?

Eight year old: 'Cause water evaporates up in the sky and it forms that cloud, and the cloud drops get too heavy.

A given student's answers to questions about clouds might fall into a different category from his or her answers about thunder, so we generalized about a student's understanding of weather according to which developmental stage predominated. For example, student #10, from the second grade class using the hands-on approach, gave religious finalistic responses to questions on thunder, artificialistic responses to questions on rain, and nonreligious finalistic responses to questions concerning wind, clouds, lightning, snow, and rainbows. Based on the

Table 1



frequency of responses, we identified this student as one with a nonreligious finalistic view on the concept of weather.

What We Found

Our results, summarized in Table 1, showed that, while some students in fifth grade had reached the stage of true causality, the majority of student in both grades were at the stage of nonreligious finalism. The data and analysis results provided support for the following statements:

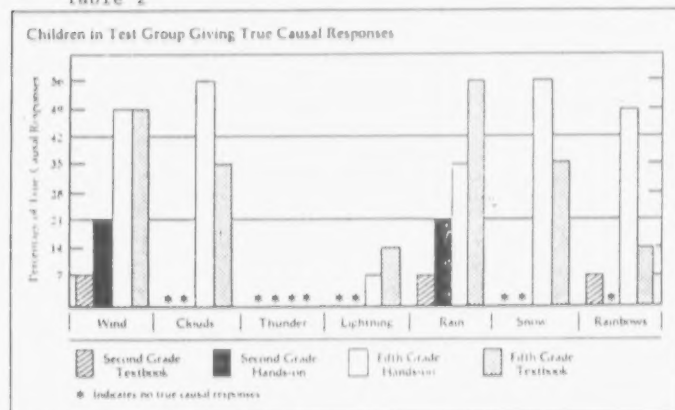
- * The only animistic views were given by second graders using textbooks.
- * More second graders gave religious finalistic responses than fifth graders.
- * Although no second grader's understanding of weather had attained the true causality stage, nearly 25 percent of fifth graders had reached that stage.

Table 2 shows the percentages of students from each class who gave true causal responses for each of the seven phenomena. The following statements were supported by the data and the analysis:

- * More second graders who were using the hands-on approach gave true causal responses to questions about wind and rain than second graders using textbooks.
- * More fifth graders who were using the hands-on approach gave true causal responses to questions about clouds, snow, and rainbows than fifth graders using textbooks.

- * More fifth graders using textbooks gave true causal responses to questions about rain than fifth graders using the hands-on approach.
- * More fifth graders gave the true causal responses than second graders on all topics except thunder.
- * no one gave a true causal response to questions about thunder.
- * More students using the hands-on approach gave true causal responses to questions about wind, clouds, snow, and rain than students who were using textbooks.

Table 2



IB. The nature of life and of what it means for something to be alive are ideas commonly encountered by children. Elementary science textbooks begin developing the concept of "living things" as early as kindergarten by

giving examples of, and making distinctions between, living and non-living things. By second grade, some textbooks have presented fairly complete definitions of the concept of life. Do children incorporate these textbook definitions into their personal world view? Or, do more "primitive" conceptions of "life" persist, in spite of our textbooks and teaching? Our second study was designed to find answers to those questions by: 1) identifying conceptions of "living" and "non-living" held by a group of fifth graders, and 2) examining the way concepts of "living" and "non-living" are presented in the elementary science textbook to which the students had been exposed.

Thirty students were randomly selected from a group of 102 fifth graders from two different schools. Each of the 30 fifth-graders was individually interviewed concerning 11 living and non-living objects. The living objects were a worm, a leaf, a tree, and a flower. The non-living things consisted of the sun, a candle, a bicycle, wind, a volcano, water, and lightning.

The interview strategy and some of the objects used were modeled after those used by Piaget. Each interview lasted 15-20 minutes and was recorded on tape. The interview went something like this: "John, is the sun alive?" Following the child's response, the interviewer asked, "Why do you think so?" After responding to the 11 items, the child then was asked: "What does it mean for something to be alive?"

Table 3 shows the number of students and percentage who said an inanimate object given was alive. Out of 30 students interviewed, a great many attributed life to non-living objects.

TABLE 3

Object	Number of 5th Graders Who Said the Object Was Alive (N = 30)	% of 5th Graders Who Said the Object Was Alive
Sun	16	53
Candle	14	47
Water	19	62
Lightning	24	82
Wind	23	79
Volcano	22	76
Bicycle	11	36

TABLE 4

<i>Is the sun alive?</i>	<i>Is a candle alive?</i>	
No, because . . . - Too hot for anybody to live on it. - Doesn't have heart. - Doesn't eat. - Doesn't move. - Doesn't do anything but glow - Made of clouds of gases.	No, because . . . - Doesn't have heart. - Doesn't move. - All it does is burn. - You have to make it move through your strength. - You can blow it up. - Doesn't have brain. - Have to light it to make it alive. - Just sits there. - Wax is not alive. - Flame eats but not much.	
<i>Is a bicycle alive?</i>	<i>Is a volcano alive?</i>	
No, because . . . - Can't move by itself - It's made of metal, tube and rubber. - Can't talk. - It takes human power to move it. - It's dead until you get on it. - Doesn't eat. - Just sits there unless you decide to move it.	No, because . . . - It's made of dirt. - Doesn't move by itself. - It is just made of hot stuff.	
<i>Is water alive?</i>	<i>Is lightning alive?</i>	<i>Is wind alive?</i>
No, because . . . - Doesn't eat anything. - Doesn't grow. - Just sits or just runs. - You can do anything you want with it. - Can't get up and walk around by itself. - Doesn't need anything to grow.	No, because . . . - Comes around once in awhile. - Doesn't eat anything. - Doesn't grow. - It isn't around all the time, only when it wants to rain.	No, because . . . - It's just air that is floating. - Doesn't need food or water. - Doesn't have heart or anything. - Lord has to make it.

Table 4 summarizes the reasons given by these students as to why they thought an inanimate object was alive. The responses were listed in order from most to least frequent. These responses are particularly interesting in light of the fact that most of these students had studied the concept of living and non-living as part of their science program for five or six years.

TABLE 5

<i>Is the sun alive?</i>	<i>Is a candle alive?</i>	
Yes, because . . . - It shines. - It pours heat. - It is moving. - It has energy which keeps us alive. - It got earth together to make life. - It keeps the solar system and universe alive.	Yes, because . . . - It has fire. - The flame is. - It burns. - It is moving. - When you light it you give life to it. - It is made of wax and wax was once a living thing.	
<i>Is a bicycle alive?</i>	<i>Is a volcano alive?</i>	
Yes, because . . . - It moves and it turns. - When you ride it, it is. - You can pedal it. - Chains and gears work.	Yes, because . . . - Can explode. - Can erupt. - It erupts when it wants to. - We say it's "active."	
<i>Is water alive?</i>	<i>Is lightning alive?</i>	<i>Is wind alive?</i>
Yes, because . . . - It moves. - It flows. - Running water is. - It has insects, fish, bacteria and plants living in it. - Is made of living molecules. - It dissolves. - It gets hot, evaporates, goes to the sky, gets big and then gets down.	Yes, because . . . - It strikes. - It moves. - It's full of electricity. - It gives out light and can show you things. - It's partly fire and fire is alive, because humans can't make it. - It can shock you. - It makes noise.	Yes, because . . . - It moves. - It blows. If it didn't it'll be dead. - It can grow. - It has molecules.

Table 5 summarizes reasons given by those students who said the inanimate object was not alive.

None of these students had difficulty identifying living things such as a tree, a flower, a worm, and a leaf. Textbooks usually mention these things as examples of living things. The reasons that children gave for the living things to be alive to a large extent matched the criteria provided by most elementary science textbooks for living things. The most frequent reasons given included movement, growth, needing food and water.

However, the results of Tables 4 and 5 show that most children focus on only one attribute of the object. In most cases an action of the object seemed to be a sufficient condition for the child to call it alive. The majority of those who said lightning was alive gave striking and moving as criteria. Other actions used as criteria included the ability to explode or erupt as in the case of the volcano. Some students considered the sun and the candle to be alive because of their ability to produce heat and light.

Some students who said that the inanimate objects were not living used the absence of certain organs like heart, brain, arms, or legs as justification. Others used the lack of certain functions such as eating, breathing, growing, and inability of the object to do things on its own as criteria for something not being alive.

Table 6 summarizes students' responses to the question, "What does it mean for something to be alive?" Most of the responses deal with attributes associated with living things and are given in elementary science textbooks and/or deal with animal characteristics such as having feelings, walking, or being happy.

TABLE 6 What Does It Mean for Something to be Alive?
(In order of frequency)

-
- To move, drink, and eat.
 - To move, to grow, and to breathe air.
 - Moves, walks, and talks.
 - Move and have feeling.
 - It can live.
 - To move and have fun.
 - To be able to think, to move, to grow.
 - Is independent, can move without anything else's power, can get its own food and water.
 - Live without humans.
 - To grow, to learn things, and live in a house.
 - To be happy and have friends.
 - To have to feed it.
 - To be a human being.
-

The results of these studies suggest that the children included in these studies were not capable of applying or transferring the information covered in their textbooks.

The results reported here are indications of what Sund refers to as "pseudo learning" [15]. Children are forced "to parrot" information and quite often we are deceived about what is learned and what is not because in our evaluation what we require children to do is parrot back to us what we have given to them.

Sund illustrates this point with a story. It seems that Piaget and his son were walking past a lake. Piaget asked his son, "How was the lake formed?" His son replied, "A giant threw a rock and made it." Piaget told him that it was not so and described how the lake had been formed by a glacier. He then asked him to repeat his explanation to ensure that the boy understood, and it appeared that the child did. Several months later, Piaget and his son again passed the same lake, and Piaget asked him how it was formed. The boy said, "A giant threw a rock and made it."

The explanation was maintained in spite of the previous efforts of the child's father. The point is that it was too early to introduce the concept and the child was not cognitively ready to incorporate the adult's explanation for the information of the lake.

The results of this study cause us to ask such questions as: Do we give the child the opportunity to share his views in the learning process? Do we have him see that there are, in fact, other viewpoints on the same concept and that the viewpoint of the book and the teacher is just another one? Are we in a hurry to correct the child's view and present, or impose on the child the adult's (scientist's) view of things?

We try to teach by lecturing--telling, rather than providing the learner with the opportunity to remove his naive conceptions in an effective manner. We spend considerable time and children use much of their energy trying to learn concepts like living and non-living.

The student's inability to understand the concept and to apply information may stem from some of the following factors:

- * the concept was introduced too early;
- * the concept was not developed properly;
- * no attention was given to what the child brought to the learning environment;
- * the concept was introduced only verbally--no "hands-on" or other interaction with the ideas took place.

As educators we should take the time to talk to students, to find out how they view things, and to try to incorporate their way of looking at things in the development of concepts. We should provide the learner with some ownership in the development of the concept. We should give students the opportunity to see that it is perfectly acceptable to have different viewpoints on a given phenomenon or concept. If we educators believe that a major purpose of education is to remove the misconception held by the learner, we need to (a) identify the naive conceptions held by learners, and (b) decide on proper time and effective methods to remove those naive conceptions.

Researchers in this area maintain that educators needs to look at and start with the learner's view and conception of the topic at hand [2, 3, 6, 10, and 16]. Some of these authors recommend that in order to bring about significant accommodations in the learner, the following steps should be taken, when introducing a new science concept:

- * Provide the learners with a challenging situation--a situation which will bring to surface students' preconceptions (a discrepant event, for example).
- * Allow students to share their views on the situation with others in the learning environment.
- * Present the "correct" view as just another view.
- * Provide students with the opportunity to discuss the pros and cons of each view presented (including the "correct" view) and if appropriate, test the various views.

- * Help students in their search for solutions and accommodations—do not continually provide "ready-made" knowledge.

II. In raising our second question, we were interested in the conceptual change between students at different educational levels [13]. The example we chose for this purpose deals with sinking and floating of objects in liquids. We used the clinical interview for detecting students' level of understanding conceptions and conceptual change. During the interviews we used items similar to those employed by Carpenter [1] at the University of Nebraska: a small wooden cube, a large wooden cube, a small metal cube, a looped wire, a large metal cylinder, a small metal cylinder, an aluminum sheet, a crumpled aluminum sheet, a clay ball, a clay pot, a jar lid, and a jar lid with holes. The objects enabled us to evaluate how students related the facts of mass, volume, density, surface tension, water pressure and buoyancy to sinking and floating.

We began each interview with, "If I place this object in this much water, will it float or will it sink? Why?" We formulated the follow-up questions according to the student's response. If a student said, "This object will float because it is made of wood," the interviewer might ask, "Does wood always float?" If a student said, "This object will sink because it is heavy," the interviewer might ask, "Are all ships that float on water light?"

To organize our data, we categorized the responses as complete understanding (CU) when students were correct in

their predictions and gave a completely correct explanation; as partial understanding (PU) when they gave partially correct explanations, although their predictions may have been correct; and as no understanding (NU) when they gave incorrect predictions and incorrect explanations.

Figure 1. Percentage of students who understand concepts related to sink/float concepts. Students display complete understanding (CU), partial understanding (PU), or no understanding (NU).

Object	Primary (K-3) N:36			Intermediate (4-6) N:40			Junior High (7-8) N:56			College N:52		
	CU	PU	NU	CU	PU	NU	CU	PU	NU	CU	PU	NU
Large wooden cube	0	62	38	0	78	22	2	84	14	2	70	28
Small wooden cube	0	88	12	0	90	10	4	91	5	2	78	20
Small metal cube	0	100	0	0	97	3	0	98	2	0	100	0
Looped wire	0	38	62	0	72	28	0	34	66	2	58	40
Large metal cylinder	0	100	0	0	97	3	0	87	13	0	96	2
Small metal cylinder	0	81	19	0	90	10	0	89	11	0	79	21
Aluminum sheet	0	88	12	0	85	15	0	82	18	4	83	13
Crumpled aluminum	0	65	35	0	45	55	0	43	57	2	71	27
Ball of clay	0	100	0	0	90	10	0	91	9	4	90	6
Pot of clay	0	89	11	0	70	30	0	73	27	6	79	15
Jar lid	0	88	12	0	88	12	0	93	7	2	98	0
Jar lid with holes	0	35	65	0	15	85	0	7	93	0	8	92

Our percentages in Figure 1 show that there is little difference in understanding of sink/float concepts among students at the various academic levels. This stands in

contrast to Piaget's theory that students past age 11 or 12 should have developed the formal logical structures needed to understand density. We found that a large number of college students said that when you crumple an aluminum sheet, you have made it heavier. This response is similar to that given by some of the elementary school children.

If you compare the CU responses in Figure 1, you find that college students did slightly better than younger students when explaining and predicting the results of aluminum and clay objects and the looped wire but that the differences are very small.

We did find one distinguishing characteristic, however. Students at the various levels used significantly different language to describe concepts. Terms such as light, heavy, and weight used by the elementary students were replaced by density, physical properties and surface tension at the junior high level.

Unfortunately, the junior high students' increase in sophisticated science vocabulary was not accompanied by increased understanding. In a similar pattern, the college students used the terms surface tension, displacement, surface area, volume, and mass but had little understanding of the concepts the terms described.

Apparently, the elementary students were giving responses based on common sense and had not yet been encumbered with scientific terminology. On the other hand, many of the older students seemed to be so concerned with trying to fit the correct scientific terms into their explanations that they lost sight of the phenomena at hand.

What does this say to teachers? That we are not spending enough time on terminology as we teach concepts or

that we emphasize terminology so much that our students lose sight of the concepts behind the vocabulary? It may come as no surprise to us that elementary students have little knowledge of science; we have evidence that science is not emphasized enough at the elementary level [8,10]. What is surprising are the results from the junior high students and, even more so, the results from the college students. The junior high students were enrolled in science courses at the time of the interview, and the college students had taken science courses in junior and senior high school. Furthermore, many of the college students had also completed several college science courses. What were they taught? What did they learn? But most important, what can we do to solve this problem?

III. The third question which we considered in our study was what are some instructional practices which can be effective in bringing about conceptual changes in students. The most effective practices follow a model similar to the learning cycle. The model uses the following steps:

1. Provide students with a situation to make predictions.
2. Have them expose their views (beliefs) by sharing predictions (explanations).
3. Allow them to test their views.
4. Help learners to resolve conflict between their views and actual observations by working with materials.

5. Help learners to make the phenomenon a part of their conceptual structure by relating (connecting) what is learned to other situations.

Using the sinking and floating of objects in liquids as an example, we compared the effectiveness of two models in bringing about a conceptual change in the understanding of students of the phenomenon [14].

The learning cycle is an instructional model proven effective in bringing about a conceptual change and consists of the following steps:

- provide learners with opportunity to make predictions;
- allow learners to expose their beliefs by sharing predictions and explanations;
- help learners to test their own beliefs by working with physical situations;
- provide the learner with the opportunity to resolve conflict between their own beliefs and their observations; and finally,
- help the learners to make connection between what is learned and other situations.

We conducted a study comparing the effectiveness of the learning cycle with the expository model consisting of teacher lectures, written problems and teacher conducted demonstrations.

The students in both classes were interviewed individually and in private--both prior to being taught the sink/float unit and after. These interviews were tape recorded. The interview format consisted of holding an object and asking the student: "If I place this object in this much water, would it float or sink and why?" The objects were similar to those used by Carpenter (1981) and consisted of the following:

- small wooden cube
- small metal cube

same
size

- large wooden cube

- sheet of aluminum foil
- folded sheet of aluminum foil

same size
sheet before
folding

- ball of clay
- pot of clay

same
mass

- jar lid
- jar lid with holes

same material
and size

In each case, after the students predicted and explained their reasoning, follow-up questions were asked to make sure that the interviewer had a fair assessment of student understanding of the concept. Finally the students summarized their knowledge of sink/float concepts by responding to the question: "What factors influenced whether an object will sink or float?" Appendix 1 outlines a portion of an interview with one of the students.

Figure 2

Percent Gain of Correct Responses for Expository and Learning Cycle Groups

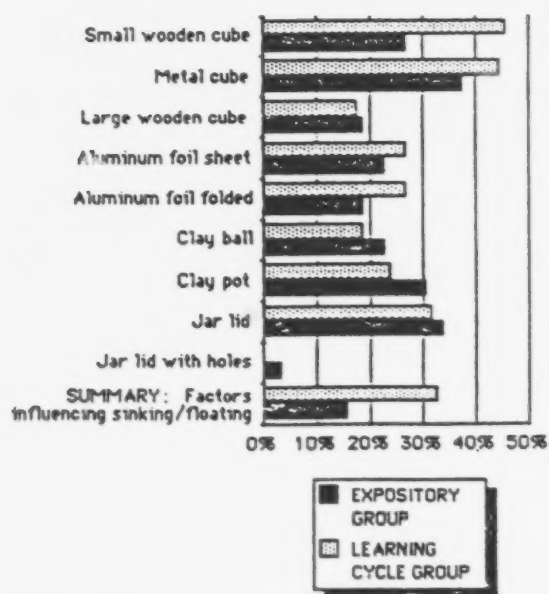


Table 7 and Figure 1 summarize the results for both groups. They compare the percent of students giving correct responses on the initial interview with those on the final interview. In order for a response to be correct, an

accurate prediction and explanation had to be given. The results also give the percent gain in the correct category for each item for each group.

TABLE 7 - Percent of Correct Responses and Percent Gain for Expository and Learning Cycle Groups

ITEM	EXPOSITORY GROUP			LEARNING CYCLE GROUP			Percent Gain
	Pre-Interview % Correct	Post-Interview % Correct	% Gain	Pre-Interview % Correct	Post-Interview % Correct		
Small wooden cube	0	27	27	4	50		46
Metal cube	0	30	30	0	45		45
Large wooden cube	0	19	19	4	22		18
Aluminum foil sheet	8	31	23	0	27		27
Aluminum foil folded	4	23	19	0	27		27
Clay ball	4	27	23	4	23		19
Clay pot	0	31	31	12	36		24
Jar lid	0	34	34	4	36		32
Jar lid with holes	0	4	4	0	0		0
SUMMARY: Factors influencing sinking/floating	24	50	16	31	64		33

Only a small percentage of students in both groups gave responses which could be placed in the correct category during the initial interview. The results are similar to those of Shepherd and Renner who found that none of the high school students in their study exhibited a sound

Percent Gain in Appropriate Use of Sink/Float Terms

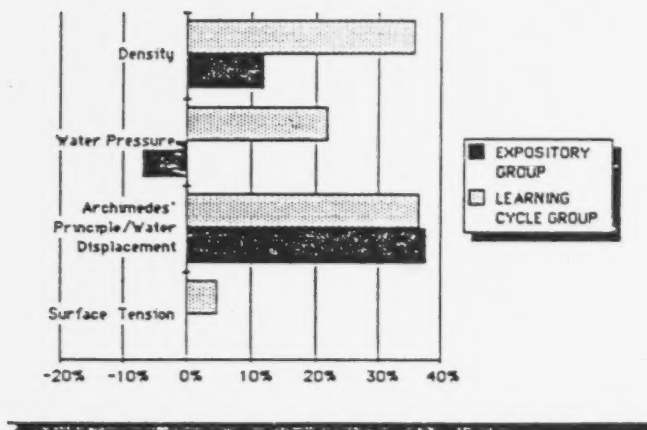


TABLE 8 - Percent of Students Using Sink/Float Terms in the Appropriate Context on the Summary Question

Term	EXPOSITORY GROUP			LEARNING CYCLE GROUP		
	Pre-Interview Percent	Post-Interview Percent	Percent Gain	Pre-Interview Percent	Post-Interview Percent	Percent Gain
Density	23	35	12	19	44	36
Water Pressure	30	31	-7	19	41	22
Archimedes' Principle/Water Displacement	0	30	30	4	41	37
Surface Tension	4	4	0	4	9	5

understanding of the concept of density of water as it related to the spring and fall turnover in lakes [9].

However, on our summary question in the initial interview, 34% of students in the expository group and 31% of those in the learning cycle group were able to correctly identify at least two factors which cause an object to float/sink.

Further analysis of the interviews was done to study the difference in the effects of the two models in bringing about a change in students' understanding of concepts related to sinking/floating. Analysis of the data (Table 8) showed that both groups improved in the appropriate use of such terms as density, water pressure, displacement, and surface tension.

In all but one instance, the learning cycle group showed a greater gain in the use of these terms when compared to the gain achieved by the expository group. The single exception being Archimedes' Principle in which the gains were nearly equal. For example, on the last question, "What factors influence sinking and floating of objects?" the learning cycle group showed gains over 20% higher than the expository group in the correct use of density and water pressure (See Table 8 and Figure 2).

The expository group actually showed a seven percent decline in their understanding of water pressure on the post-test. This difference may not be significant, but it could point out that the lecture-recitation form of science teaching can, at times, confuse students about abstract concepts and that the memorization of terms, facts, and formulas does not result in real learning when students are concrete operational.

Examples of the appropriate uses of the terms related to sinking/floating given by students appear in Table 9.

TABLE 9

Examples of Student Comments Using Terms in the
Appropriate Context in the Pre- and Post-Interview

- Density - The wooden block floats because its density is less than that of water.
- Water Pressure - The weight of the aluminum foil is spread out over a large area. It will lay on more water and the pressure from the water will help it to float.
- Archimedes' Principle/Water Displacement - The clay ball will sink, it weighs more than the volume of water it is going to displace.
- Surface Tension - the aluminum sheet will float. The surface tension, something about the water molecules sticking together, might hold it up.

TABLE 10

Inappropriate Use of Terms

- Density - the aluminum sheet will float because of its weight which is low and its high density.
- Water Pressure - the sheet of aluminum foil would float. It's covering a lot of area. Air would be trapped between the foil and water. The air wouldn't get pressed under the water and isn't very heavy
- Archimedes' Principle/Water Displacement - What determines whether an object will float or not is displacement. Density would determine that weight, how heavy an object is.
- Surface Tension - Small metal cube will sink because the weight is more concentrated and the surface tension maybe?

Table 10 provides examples of inappropriate uses of these terms.

It should be pointed out that in neither group did the number of correct responses exceed 50% for any of the objects used in the interview. One might question why the total number of responses was not higher. One possible explanation is that concrete operational students have difficulty learning formal concepts [5]. Preassessment studies of several sections of the science content courses which served as the source of subjects for the study, revealed that about one-half of these students are operating at the concrete or concrete transitional level. Another factor which may have been at play in this study was that of misconceptions held by students. Eaton, Anderson, and Smith found in their study with students considering "how light helps us to see" and "where do plants get their food," that if students approach a topic without knowing anything about it, they may be willing to consider any information their teacher presents [3]. However, if students already have ideas about a topic, these ideas can interfere with their ability to understand. The subjects of our study were college students and obviously many had previous ideas about the concepts.

Another comparison can be made between our study and others cited in the literature with respect to the improvement shown by the learning cycle group when compared to the expository group. In the study of 10th-grade students' understanding of matter and density changes, Shepherd and Renner found a significant gain in favor of students at a concrete operational level who were taught through first-hand experiences as compared to students taught concrete concepts formally [9]. Thus, concrete instruction (learning cycle) may be preferable to formal instruction (expository) because concrete instruction

promotes superior cognitive development of concrete level thinkers [8].

DISCUSSION

Based upon post-session interviews, both groups showed considerable gains in understanding the concepts involved in sinking/floating. Except for one object (jar lid with holes) gains in the percentages of students giving correct responses ranged from 15 to 46 percent. The overall gains of the learning cycle group were slightly higher than those of the expository group. In two instances, the small wooden cube and the summary statement on factors influencing sink or float, the percentage gains for the learning cycle group were considerably higher than those of the expository group. Our results suggest that college students' understanding of science concepts dealing with sinking/floating may be improved by using a teaching style which combines demonstration with lecture or the learning cycle model. The latter model generally yielded a higher percent of correct responses than did the expository model.

Both teaching models in our study were effective in bringing about a change in students' understanding of concepts associated with sinking and floating when applied to most of the objects. However, neither model brought about a change in students' responses associated with the floating of jar lids with holes. (In neither group were objects with holes used in sink/float presentations.) This may be an example of learners holding on to their original conceptions regardless of the type of instruction they receive. This may be due either to the fact that learners were more influenced by their own perceptions than by their understanding of the concepts or the instruction did not adequately address the surface tension and its effect of float and sinking. Possibly, in the case of certain science

concepts about which a large number of students exhibit misconceptions, we need to design and use alternative models of instruction if we are to correct student misunderstandings.

Summary

In this paper, the researchers considered student misunderstandings of some common science concepts involving explanations of weather phenomena and criteria for distinguishing living from non-living. In this section we have made some suggestions on how to bring about accommodations in the learner when introducing new science concepts. We have also looked at patterns in student misunderstandings of concepts involved in objects sinking and floating. Misunderstandings by students at the elementary, junior high school and college levels were studied. Finally, we have suggested some instructional practices, based on our research and that of others, which may be used to bring about conceptual changes in students.

References

- [1] Carpenter, E. G. Piagetian Interviews of College Students. In Fuller, E. G. (Ed.), Piagetian Programs in Higher Education. University of Nebraska, Lincoln. 1981.
- [2] Cohen, M. "How Can Sunlight Hit the Moon if We Are in the Dark?": Teachers' Concepts Of Phases of the Moon." Paper presented at the Seventh Annual Henry Lester Smith Conference of Educational Research, Bloomington, Indiana. 1981.
- [3] Eaton, J. F., Anderson, C. W., & Smith, E. L. "When Students Don't Know They Don't Know." Science and Children. 20(7). 1983.

- [4] Fuson, K. "Piagetian Stages in Causality: Children's Answers to 'Why'?" Elementary School Journal, 77, 150-157, 1976.
- [5] Lawson, A. E., & Renner, J. W. "Piagetian Theory and Biology Teaching." American Biology Teacher. 37(6), 1975.
- [6] Nussbaum, J. & Novick, S. "Creating Cognitive Dissonance Between Students' Preconceptions to Encourage Individual Cognitive Accommodation and a Group Cooperative Construction of a Scientific Model." Paper presented at the AERA Annual Convention, Los Angeles, California. 1981.
- [7] Piaget, O. "The Child's Conception of the World." Totowa, N.J.: Littlefield, Adams. 1969.
- [8] Schneider, L. S. & Renner, J.W. "Concrete and Formal Teaching." Journal of Research in Science Teaching. 17(6), 1980.
- [9] Shepherd, D. L. & Renner, J.W. "Student Understandings and Misunderstandings of States of Matter and Density Changes." School Science and Mathematics. 82(8), 1982.
- [10] Smith, E. L., and Anderson, C. W. "Planning and Teaching Intermediate Science: Progress Report". NSF Grant, Michigan State University. 1981.
- [11] Stepan, J. I. "Biology in Elementary Schools: Children's Conceptions of Life." The Biology Teachers. 47, 222-225, April, 1985.
- [12] Stepan, J. I. and Kuehn, C. "Children's Conception of Weather." Science and Children, 23, 44-47, September, 1985.
- [13] Stepan, J. I., Dyché S., and Beiswenger R. "The Effects of Two Instructional Models in Bringing About A Conceptual Change in the Understanding of Science Concepts by Prospective Elementary Teachers." Science Education. To Appear.
- [14] Stepan, J. I., Beiswenger, R. E., and Dyché S. "Misconceptions Die Hard." The Science Teacher, 53 (6), September, 1986.
- [15] Sund, R. B. "Piaget For Teachers." Columbus, Ohio: Charles E. Merrill Publishing Company. 1976.
- [16] Za'rour, G. I. "Science Misconceptions Among Certain Groups of Students in Lebanon." Journal of Research in Science Teaching, 12:4, 1975.

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People in science education seem quite taken in recent years by what they term a "constructivist epistemology." I have found their use of the term increasingly puzzling. Often it seems to me to function in the discourse of science educators rather like the word "democracy" functions in political discussions. Democracy is presumed to be a good thing whatever it is. That any two people mean the same thing by it is, however, in doubt.

But "democracy" is also a useful word if only because it unites people who in reality do not agree about very much in a sense of common enterprise. Perhaps it at least serves to remind people that they share a common political tradition or that they share common antagonists. "Constructivist" may function in a similar way. Whatever it means, if we are constructivists, at least we know that it is important to be interested in children's misconceptions, to describe how they think about science, that we have Piaget as part of our heritage, and that behaviorists are the bad guys. Loyalty and group identification is made of such stuff. Clarity and intellectual progress are not.

I do not propose to ask what "constructivism" really means. Instead, I propose to ask whether there is anything for it to mean that makes sense. I shall proceed as follows. First, I shall examine two ideas that seem common among people who call themselves constructivists. These are: (1) the idea that the mind is active in constructing knowledge; and (2) the idea that concepts are invented rather than discovered. I shall argue that the problem with these notions is that they can be explicated in a variety of ways. Some of these ways turn out to be rather obviously true. At least they are denied by virtually no one worth taking seriously. Others turn out to be unsustainable. At least, when

followed out consistently, they have very high epistemic costs. The trick is to find some middle ground. Is there some formulation of constructivism that is neither uninterestingly true nor patently objectionable?

To attempt to answer such a question in a brief paper would be the height of hubris. It would require solving most of the central problems of epistemology. I propose instead to discuss two tests for the adequacy of any variety of constructivism. The first is the test of objectivity. Constructivists need not believe in certainty. They need not believe that ideas are true in virtue of their correspondence to reality. But, unless they wish to give expression to a kind of epistemic death wish, they must believe that some ideas are better than others because it is under the circumstances more reasonable to believe them.

Second, constructivists must make sense of the public character of knowledge. It may be true that people construct their own ideas. But it is also true, obviously true, that people assert meaningful utterances to one another from which they learn. Any view that suggests that knowledge once acquired cannot be transmitted by language is absurd.

I use these tests because they seem to me to touch the particular liabilities of constructivists. As constructivists begin to explain what they mean by the claim that people actively construct their concepts, they face the danger of lapsing into relativism and privacy. The problem for constructivists, then, is to find something to mean by "constructivist" that is not trivially true that does not yield to these forms of epistemological suicide.

The mind is active

Constructivists want to claim that people are active in constructing their knowledge. What might this mean? Generally, when philosophers talk about the concept of action, they oppose activity to passivity, to merely undergoing something. To illustrate, "I went to the store" suggests

that going to the store is something I did, whereas in "I fell down the stairs," falling down is something that happened to me.

Note that being active has little to do with how much motion occurred or how much effort is expended. My body may move a great deal in falling down the stairs, and I may expend a lot of effort resisting the fall. But falling continues to be something that happens to me, not something I do. In contrast, turning my head or paying attention is active. Whether my behavior is active or passive has to do with the connection between my intentions and what is going on with me--not with motion or energy expenditure.

Let us suppose that this is what we mean when we say that people are active in constructing their knowledge. That is, we mean that constructing knowledge is something we do, not something that happens to us. Who is excluded by this formulation? Among philosophers, I would suggest that the answer is that we have left out almost no one. But surely, some will reply, many people in the empiricist tradition treat knowledge as passively acquired. I think this is simply untrue.

Consider the most plausible candidate for passivity. Some empiricists have likened the mind to a blank tablet to be written on by experience. The process whereby the mind receives its impressions from experience is described in passive language. The mind is simply written on. Experience is something that is simply had. And it is what it is. We can do nothing to affect its character. We simply undergo it. Surely, then, empiricist accounts of knowledge acquisition are passive accounts. But here we should also note that, for empiricists, having sense impressions does not constitute knowledge. Knowledge is result of what the mind does with sense impressions. Aristotle and Locke described this process as one of abstraction. It is generally described in an active language. Knowledge is something done to or with experience. I think something like this is generally true of

the empiricist tradition. Sense experience is often seen as undergone, but the process of building generalizations on the basis of sense experience is described in an active language. There are exceptions, Hume perhaps, but I suspect that what I have suggested is the rule about the empiricist tradition from Aristotle to the logical positivists of our century. Nothing about empiricism per se commits one to a passive view of knowledge.

Let us try another approach. Perhaps it is not empiricism that commits us to passivity, but the view that there are laws of learning. One might reason as follows: If there are laws of learning, then learning happens according to those laws. But insofar as behavior is governed by laws of learning, it is determined by these laws. Our intentions or our choices (if we actually have such things) are irrelevant to it. All of our behavior including our learning or knowledge production is something that happens to us. We are, in that respect, passive in all that we do.

Two points are important about this. First, there is a serious issue here. The claim that human behavior can be sufficiently explained by scientific laws has surely suggested to many that people are determined and therefore not free. Insofar as learning is governed by such laws learning will be a passive happening. On such a view human beings do not act at all. They merely undergo. The view that human learning can be explained scientifically, if one means this by it, can thus easily lead to a passive view of learning. Thus, there is potentially a heavy cost in those forms of educational psychology that attempt to work out the details of such a program about human learning.

The second point, however, is that such conclusions do not inevitably follow from the premises. B.F. Skinner, for example, may have been seduced by his respect for what he believed to be the requirements of a science of human behavior into a passive view of learning, but it is surely unwise to confuse Skinner with a competent philosopher. Generally

philosophers, even those who hold such commitments about a science of behavior, have been unwilling to follow suit. It has been more common to see human freedom or the activeness of human behavior as a simple fact to be reconciled with the existence of a scientific approach to behavior. Freedom may be seen as compatible with determinism. To be active is to act because of our beliefs or intentions. J.S. Mill and Moritz Schlick illustrate.

I thus want to conclude that philosophically the suggestion that people are active in learning or knowledge construction is rather uninteresting. It is uninteresting because almost no one, beyond a few aberrant behaviorists, denies it. I know of no tradition in epistemology whose advocates consistently deny that people are active in knowing or whose basic propositions clearly commit their adherents to such a view. Thus, the suggestion that people are active in producing knowledge seems to me to be trivially true. No one seriously believes that knowledge is something simply undergone.

I think that this point readily transfers to pedagogy. Educators often talk as though there are people out there who treat knowledge as passive. They sound as though teachers believe that knowledge can somehow be inserted into students' heads without the students' active response to it. But does anyone hold such a view, or do any common teaching practices really assume it? I find this doubtful. Consider an example.

Suppose some benighted teacher gives assignments that require only memorization, that he or she teaches only by lectures that only assert facts, and that he or she gives only tests that require the students to show that they can reproduce these facts. Does such an account require a passive account of learning? I think most of us would be inclined to say "yes." Unfortunately that response is uncritical and wrong. The correct answer is that such teaching assumes a passive account of learning only if a

passive account is given of language comprehension and of memory. But why should anyone accept such an account or why should we believe that such accounts are presupposed by asserting facts? It is surely possible to believe that when students hear what they are told, understand it, and remember it that they are engaged in cognitive activities. Indeed, I will wager that most people who call themselves constructivists are quite committed to the view that listening, understanding and remembering are cognitive activities. Why, then, is the verbal transmission of information stigmatized with the label "passive learning" or otherwise described with passive language such as "rote learning"?

I think that the answer is that "passive" is a pejorative term. As such it is an effective tool for insulting views one dislikes. That it is generally meaningless or inappropriately applied does not necessarily reduce its effectiveness.

I do not, of course, mean to commend teaching methods that proceed solely by asserting facts. There are numerous issues raised. What is a fact? Need all assertions be assertions of facts? What else is there to teach; theories, meanings, concepts, critical thinking? What do these terms mean? How are they different from facts? Once we know what they mean, how do they relate to one another? When we have an adequately understood inventory of cognitive concepts, how do we order our preferences among them so far as teaching is concerned? And once we have achieved clarity about what we want in teaching, how do we teach? Especially, what is the role of direct verbal instruction in effective teaching? How do words work? How does language get to be about the world?

These are some of the epistemological questions that need to be addressed to appraise direct verbal instruction or, for that matter, to appraise almost any kind of instruction. The distinction between active and passive learning seems largely to obscure these questions. So far as I can see, it does little useful intellectual work unless insulting and con-

founding one's enemies and forging bonds of solidarity with one's friends is seen as useful work. Given the sense of active learning I have been dealing with, it is something everyone can support. It is trivially true.

Now perhaps this is because I have chosen a concept of activity that is too broad. Perhaps active learning should involve more real moving about or more real reorganization of cognitive input. I suspect that there are numerous ways to up the ante on what is meant by "active" so that we might exclude some views. Obviously I cannot take on all comers. But the task is to find some more restrictive sense of active that does not exclude too much. To take the most obvious case, surely people do, in fact, learn with comprehension ideas both simple and complex because they hear other people say them or because they read what others have written. A view of learning that treats the verbal transmission of facts, concepts, or ideas as inevitably passive or as otherwise objectionable is merely stupid. A concept of activity that leads to this judgment is defective for that reason. Of course there are conditions for meaningful discourse and not all discourse is meaningful. Of course one can teach without just telling people what you want them to learn. That is not my point. Rather, the point is that people often seem to learn by listening to what others say. A view of activity that renders such obvious facts problematic is wrong. It is not obvious to me that one can expand the meaning of "activity" beyond the initial meaning I have suggested without encountering such difficulties. I thus suspect that the claim that learning or producing knowledge must be active will turn out to be either trivially true or patently false.

Consider one more possibility. Constructivists often seem to suggest that the activity of the mind is most clearly revealed, especially in verbal learning, in that what is learned is not precisely what is said. Rather each of us actively interacts with what we hear or see in interpreting input within our own unique set of meanings. The product of

learning is thus uniquely ours. That it is uniquely ours is a sign of the activity of our minds.

Two points are required here. First, again, it seems to me that almost all viewpoints in the history of philosophy will agree with some formulation of this point. Even the most traditional of empiricists recognize interaction between new experience and old or between current experience and prior concepts. (Sometimes this was seen as a bad thing. It is part of the empiricist account of biased judgment.) That the new interacts with the old is not news. All of the interesting questions concern the details of this interaction.

Second, I think that it can be argued that the constructivist emphasis on the individuality of cognitive constructs stands a classical philosophical problem on its head. For most philosophers it is the fact that sometimes we do manage to make ourselves understood and that we (collectively) manage to have publicly communicable knowledge about a common world that has been the phenomenon of interest. The question has been to understand how this is possible. Given the diversity of human experience, language and culture, how is it that we seem to such a remarkable degree to live in a common world so that even our mistakes about it often have a public structure? The remarkable thing about our individual cognitive structures is that they are not so unique that we cannot generally succeed in effectively communicating with one another about a common world. The philosophical task is to understand how this is possible. That constructivists sometime want to revel in the potential Babel implicit in the diversity of our cognitive structures seems to me to be a prime example of the epistemological death wish to which its adherents often give voice. Again, the constructivist is on the horns of a dilemma. It is clear enough that, in some sense, the old interacts with the new. That is true, but uninteresting. The task is to explicate the details in a way that allows us to understand the fact of meaningful communi-

cation, the sharing of common concepts, and the fact that we live in a common world.

Knowledge is invented, not discovered.

Constructivists, however, have more invested in the view that knowledge is a construct than in the idea that it is actively constructed. We need to look at the idea that knowledge is a construct.

Often the idea that knowledge is constructed is juxtaposed to the view that it is discovered. Let us explore that idea for a while.

In one sense there is something fairly obvious about the claim that ideas are not discovered in the way in which islands or stars are discovered. One does not go looking for ideas as though they could be found in a place. In the sense of "discover" involved here, objects of discovery are things that have location. To discover them is to locate them. Knowledge lacks a location. Thus it is not the sort of thing that can be discovered if that means to locate its place. All this is obvious.

But the idea that knowledge is constructed, not discovered, seems meant to suggest far more than that knowledge is not locatable as though it had a spatial location. Rather the point of talking about knowledge as a construction is to suggest that it has a kind of made-up quality about it. What needs to be made sense of is just what this made-up quality amounts to.

Consider one thing that might be meant. Suppose we were to hold that the basic nature of reality was not apparent to observation. The ideas we need to understand reality are not among its surface features. It would then follow that those concepts that are required to grasp reality properly are not in some way available to be discovered. They must be creations of the imagination.

Now this is a familiar view in philosophy. It suggests that an important distinction may be made between appearance

and reality. The nature of things is not revealed by its surface appearance. The view comes in many variations. It is expressed in Plato's distinction between the world of appearances and the world of forms. Surely it is also a part of the view of modern science. The kinds of concepts that scientists use to construct theory do not have referents that are visible on the surface of the world. We do not come across quarks, DNA molecules, or multidimensional universes by casually looking around.

This means that we must view the concepts we employ in theory construction as inventions. We make them up. We do not happen upon them.

But notice a few things about this view.

First, it is commonplace. There are few who would deny it. Certainly it will not drive even the most hidebound and orthodox of empiricists from our midst. That theoretical entities were constructs was a staple of logical positivism. Indeed, many positivists insisted that even the objects of our common experience were things we constructed out of sense data. The experience of a penny, for example, is a marvelously complex construction that the mind imposes on the assorted perspectival sense impressions that we have of pennies.

Second, it is largely a view about concept formation. It is consistent with a variety of views about the truth or the adequacy of our concepts. It is at least *prima facie* possible to believe that our concepts are inventions and that they correspond to something real. There are, of course, ways to argue against such views, but they are not patently contradictory.

Finally, this weak view of constructivism is associated with a distinction between the context of discovery and the context of justification. Philosophers who made this distinction generally were willing to admit all sorts of unpleasant things about where concepts come from so long as those admissions were confined to the context of discovery.

Perhaps concepts are made up. Perhaps they reflect our class origins. Perhaps they reflect our personal histories. Perhaps they emerge from our dreams. Perhaps that idea I woke up with this morning is the cognitive vengeance of that pepperoni and anchovy pizza I had before bed.

But none of this, so the argument goes, is of much epistemological interest. What is of interest is how we go about selecting from the store of available concepts those that are going to be taken to be reasonable, adequate, or true. Epistemology has to do with the context of justification, not the context of discovery. We can admit all sorts of dark stories about the origins of concepts, so long as none of these stories account for why we continue to accept them.

Here again we seem to have found something for constructivism to mean that is trivially true. Few in our day would argue that concepts are inventions in this sense. Is there anything more interesting for constructivism to mean?

Very often it seems to me that constructivists want to hold some thesis about the relations of our concepts to reality. Indeed, constructivism is sometimes presented as a denial of a correspondence theory of truth.

Let us do a little sorting here. First, it is important that, if we are going to explore correspondence theories, we not deny anything too silly. Empiricists once held ideas to be pictures of the world. Our ideas are true when they picture the world as it is. The objections to such a view are well known. No one holds it anymore. Generally, concepts are viewed as rules. For empiricists, the rules specifying the meaning of a term specify how the world is to appear if the term is to apply correctly to it. Various empiricist stories have to do with how direct the connection between the word and the world must be. Most stories these days see this connection as exceedingly indirect.

We must also decide what type of correspondence we wish to deny. Up to this point I have been using terms like "con-

cept," "idea," and "knowledge" loosely and interchangeably. Let me be a bit more exacting about two of these terms. I shall distinguish between concepts and propositions. The salient feature of a proposition is that it asserts something. It makes a claim. It can thus be true or false. Concepts classify. They divide the world into groupings. But they do not assert.

Now one can deny a correspondence view about either concepts or propositions or both. Let us start by denying that concepts correspond to anything. Here what one is denying is that there are any natural kinds. Our concepts cannot divide the world at its joints, because the world does not have joints. The standards to be applied to our concepts are likely, therefore, to be pragmatic ones. The most obvious pragmatic standard for our concepts is that concepts are useful when they enable us to assert true and important propositions.

It should be noted that this form of conceptual pragmatism will entail the denial of materialism. To take such a view of terms such as "electron" is to deny that there are electrons. To believe in the existence of the referents of the basic theoretical terms of physics is to believe both in the existence of physical entities and in the existence of natural kinds. Conceptual pragmatism will deny both. It is a step in the direction of idealism.

Conceptual pragmatism is also perfectly consistent with a correspondence theory of truth. Indeed, it is often explicated so as to require one. A concept that meets the pragmatic test of usefulness is one that enables us to say true things about the world, i.e., to describe the world the way it is.

Now, of course, it is quite likely that for a conceptual pragmatist what it will mean to describe the world the way it is is that we can utter sentences that assert that the world will appear in certain ways and that, indeed, the world does appear in those ways. Or it will mean that we can formulate theories from which true predictions about experience can be

deduced. In both cases, true propositions are those that save the appearances.

We should note that conceptual pragmatists are constructivists with a vengeance. They are likely to tell a Kant-like story about how our experience is a result of sense data or the given structured by our conceptual apparatus. Not only our concepts but our very experiential world is constructed.

If this is so, how is it that we live in a common world? Conceptual pragmatists can tell two stories about this. The first is a story about socialization. Concepts are social inventions. Their evolution is a social phenomenon. Individuals do not so much construct their own world as they are initiated into a common socially constructed world.

The second story is that concepts are under selective pressure from experience. The given part of our experience is what it is quite apart from how we conceptualize it. Some concepts are more or less useful in enabling us to say true things about it. Thus there is some epistemic pressure on the direction of conceptual evolution. And one might expect a degree of convergence among concepts. There are thus two stories. Let us call them the socialization story and the save the appearances story. These stories are, I think, quite consistent.

I do not think that conceptual pragmatism will do justice to what most constructivists want to say. First, conceptual pragmatism, as I have described it, is a variety of logical positivism. Constructivists seem to want badly not to be positivists. Second, constructivists seem to want to deny correspondence theories of truth in a more radical way than I have suggested. Let us consider some grounds for these denials.

One of the central features of the conceptual pragmatism that I have sketched is the view that experience can be analyzed into two components, the conceptual and the perceptual, the given. An ordinary experience is a conceptualized per-

ception. Now the conceptual element of experience is susceptible of variation. People may conceptualize their perceptions differently. But perceptions are simply given. As "the given," they are indubitable. Moreover, they can be described in a theory-neutral data language. They thus form a sort of epistemological bedrock against which our assertions can be checked.

Modern constructivists seem often to want to deny the possibility of any theory-neutral given. Often they appeal to the arguments of Thomas Kuhn. Kuhn seems clearly to want to deny that there is any given or any neutral data language. Instead, perception (not just experience) is always theory embedded. There is no part of experience that can be isolated from concepts. People who have different concepts live irreconcilably in different experiential worlds.

How does this change the picture? It changes it by rejecting the save the appearances story. Or it is often read as doing so. At least, it seems that across different theories there are no common appearances to save. But we need to be careful here. Some points to consider.

First, Kuhn's views do not entail that there are no appearances to save. Within each conceptual tradition there are appearances. And they need to be saved. The problem Kuhn points out is not the absence of appearances to be saved, but the difficulty in agreeing as to what they are between two divergent conceptual systems.

Second, Kuhn does not, so far as I can see, claim that perception is infinitely malleable to conceptualization. It may be that when Aristotle and Galileo look at pendulums they see different things, but neither of them is likely to see a giraffe. For Kuhn, perception is not mastered by will.

Third, even if it is true that there are no theory-neutral descriptions of any given datum, it does not follow that a description of some datum cannot be given that is neutral to the particular theories at issue.

All of this is to say that it is not entirely clear that Kuhn has abolished saving the appearances.

Finally, we should note that while Kuhn may have substantially weakened the save-the-appearances story, he seems much committed to the socialization story. It is the initiation of scientists into a common conceptual tradition that allows them to live in a common world. Without the socialization story, Kuhn collapses into solipsism.

Let us assume, however, that saving the appearances has become problematic because perception is theory embedded. What follows? Recall that, for conceptual pragmatists, the meaning of the correspondence between propositions and the world was developed in terms of the notion of saving the appearances. It might, then, be held that Kuhn has given the coup de grace to this version of a correspondence theory. To the extent that our experience is generated by our concepts, to that extent we discover ourselves in our experience. We can know the world because we have created it. To that extent it appears problematic to talk as though our concepts or our assertions could correspond to anything independently real.

This reading of Kuhn completes a retreat into idealism. The reality in which we live is mental. We not only construct our ideas, but in doing so we construct a world. Indeed, having fallen into skepticism and idealism, we are saved from solipsism only by a common socialization.

Now I doubt that many constructivists really want to go where this path has led. Can it be avoided? Let us approach this question first by asking if we have any remaining standards by which scientific ideas can be appraised. Let us consider two classical suggestions: consistency and workability.

It is more than clear that consistency will not take us far. Surely it is nice if our ideas are consistent. But it is also clear that there are different sets of competing ideas that are internally consistent. The point is to

discover which are true. That was supposed to be the point of the save-the-appearances story. Consistency will not get us far.

Can we defend a pragmatic view of truth? Here I want simply to note the usual difficulties with pragmatism as a theory of truth. Pragmatism tends either to lead to complete subjectivism, or it turns out to be a variant on the save-the-appearances story.

Suppose Johnny believes in Santa Claus. Suppose also that believing in Santa works for Johnny in that it makes him feel good. Moreover, so long as he believes, he gets an extra present at Christmas. Santa anted up along with Mom and Dad. His belief does no particular harm. Does this count as working? To answer "yes" is to give full expression to the epistemological death wish. There are no constraints on what can work.

Are there alternatives? Well we might argue that Johnny's belief will not stand examination in the light of various facts known to Johnny. Perhaps Johnny has no chimney. Perhaps Santa looks suspiciously like Daddy. Perhaps it is hard to conceive of the logistics required by a one man/one night planetary binge of philanthropy. Thus Johnny's ideas do not work. But here workability has come to mean saving the appearances. It has become a misdescribed variant of empiricism. Most versions of pragmatism, it seems to me, share this fate. They turn out to lead to subjectivism or empiricism.

Note again the strategy. I have proceeded to expand what might be meant by seeing ideas as constructs. What seems interesting is that at that point at which constructivism seems to begin to mean something interestingly different from what philosophers tend to commonly hold, it tends to collapse into skepticism and solipsism. But, of course, I have not shown this to be the case. I have merely suggested some reasons for the trend.

Note again the criteria to which I have generally appealed. First, I have assumed that accounts of science must give an account of objectivity. It is important here not to commit the elementary mistake of confusing objectivity with certainty. No doubt much of what we now believe will prove untrue. Only the naive are certain. But accounts of truth are accounts of what it means for an idea to be true. They need not assume that we are certain about which of our current ideas are, in fact, true. What an account of objectivity requires is that we be able to explain why, at the moment, it is more reasonable to believe one thing rather than another. Constructivists, at least in their more radical and interesting varieties, need to tell us a story that does not rely on saving the appearances. Stories about saving appearances can be converted into correspondence theories of truth.

Second, constructivists need to account for the fact that, to a remarkable extent, human beings share common concepts. The most obvious explanation for this is that concepts are not generally constructed by individuals so much as they are shared. That is, they are acquired as the result of some form of communication the primary instrument of which is language. It may be that individuals, in some sense, must construct their own concepts. But whatever this means it cannot mean that people do not communicate with one another by words. And it may be that what is said is interpreted uniquely by each individual, given that individual's current concepts. But this cannot mean that each of us lives in a private world where we hold no views in common. Stephen Toulmin expressed the right idea here. "Each of us thinks his own thoughts, our concepts we share with our fellow men."

These are not only standards that any coherent epistemology needs to meet; they are important pedagogically. In science instruction we expect students to deal with ideas that have been generated by others. These are a few among a wide range of available ideas. If they have no special

status, the curriculum is an arbitrary intervention in the free constructive activity of students. In science classes we expect students to deal with apparatus, laboratories, and experiments. Why? If these activities have nothing to do with why it is more reasonable to believe one thing than another, then these characteristic activities of science are nothing more than legitimization rituals, and we are doing nothing more than sharing with a few students the secrets of maintaining our undeserved social positions. If every idea is as good as every other and if that which certifies an idea for a particular student is the fact that it is a personal construct, it is simply mysterious as to why we should teach or why students should care what we teach.

Education is fundamentally the initiation of a new generation into a cultural heritage. Concepts are cultural artifacts that have evolved over many human generations. Children become human by internalizing some part of this conceptual storehouse. The fundamental thing about concepts is their social character. Any serious view of human learning must contend with this fact. Problems about how students can be encouraged to become comprehending intelligent people or why they often fail to be, need to be framed within this context. It is no doubt true that students must, in some sense, construct their own concepts. It is also true that no one can believe for another or feel another's pain. It does not follow that ideas cannot be communicated by words. The crucial pedagogical questions do not concern how to help students to learn without telling them what they are supposed to know. They concern the conditions for meaningful discourse.

The objectivity and publicness of knowledge thus seem to me to be the citadels of any reasonable account of teaching. It may be that a constructivist epistemology can be developed that is both true and interesting and that does not do violence to these notions. But an epistemology that does do violence to these notions is no friend to a theory of teaching.

THE IRRELEVANCE OF COGNITIVE SCIENCE TO PEDAGOGY

ABSENCE OF A CONTEXT

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I can remember being moved to the quick by Dewey's notion (set forth in Art and Experience) that mind should be conceived as a verb and not a noun, that it had to do with attentiveness, with care and solicitude, with engagement with lived situations (Greene, 1987, p. 5).

INTRODUCTION

Of late, as I've read or heard presented work done that is identified as having a cognitive orientation I've sometimes felt a vague unease. I chose my paper topic for this meeting to give me an impetus to explore systematically this unease.

When I first read cognitive psychology and cognitive science work and first learned about students misconceptions or alternative frameworks, I felt immediately the value in these ways of looking at learning and teaching. Descriptions of student misconceptions resonated with my remembrances of former students' difficulties and enriched my present practices. Cognitively-oriented work provided me with a powerful alternative to the behavioristically oriented educational theories in which I had been trained. The fruitfulness of a cognitive orientation made my present inchoate uneasiness puzzling. What finally helped me crystallize my diffuse dissatisfaction was a statement Howard Gardner wrote in The Mind's New Science.

To my mind, the major accomplishment of cognitive science has been the clear demonstration of the validity of positing a level of mental representation; a set of constructs that can be

invoked for the explanation of cognitive phenomena, ranging from visual perception to story comprehension. Where 40 years ago, at the height of the behaviorist era, few scientists dared to speak of schemas, images, rules, transformations, and other mental structures and operations, these representational assumptions and concepts are now taken for granted and permeate the cognitive sciences. (Gardner, 1985, p. 383).

The thrust of cognitive work implied by the Gardner quote moves us in a direction I think mistaken. By attempting to represent and explain knowing and knowledge it is too easy to focus on efforts to clarify terms, sharpen distinctions, develop taxonomies, and standardize methods and procedures. We begin to simplify, to construct artificial situations or clear cases to facilitate analysis. Inevitably we move away from consideration of the complexities and difficulties that led to our original efforts to look beyond behaviors, to try to understand "the learner- in-the-process-of-learning (West and Pines, 1985, p. 1)."

Gardner's quote does not apply to all cognitively oriented work, but does characterize much work, work I, as a teacher and teacher educator, fear can become irrelevant to pedagogy. Why should it matter? Because I think that pedagogy, the art and act of teaching, is the most important human endeavor there is, if not absolutely so then certainly for those of use who work in education. The generation of new understandings matters little if we cannot then use these insights to help others to see and better understand.

Pedagogical views are complex, consisting of a fusion of assumptions about learning and development, about instruction, and about human nature. The image of pedagogy that guides much of my thinking is similar to one implied by Max van Manen:

A journal of pedagogy then is a particular kind of commons, a space, which draws like-minded men and

women to engage in certain kinds of discourse, dialogues, or conversations about the lives they live together with children, adolescents, adults, or with those, young or old, entrusted to their pedagogic care.... [Pedagogy entails] a thoughtfulness about the limits and possibilities of how we speak, of the languages of common sense and science; a thoughtfulness of how we construct and perpetuate the often repressive institutional and ideological environments in which we live and in which we place our children (1983, p. 1).

In this paper I'd like to discuss three specific dangers I see inherent in the research aims stated by Gardner. These are; a reification of knowledge, a lack of concern with the contexts in which most formal teaching/learning occurs, and a denial of the emotional elements of learning.

MIND AS A VERB: REIFICATION OF KNOWLEDGE

There is lack of unambiguous definitions of terms in cognitive psychology, many kinds of methods are being used. We are still working, our conceptualizations are developing, so there is some inconsistency. However, too much focus on the methods to elicit and represent cognitive structures may generate the kind of mentalist mumbojumbo (see Greer, 1983) that gave rise to behaviorism. Scientistic pressures, which all of us have internalized to some degree, may pull us to develop general procedures and standard practices so that quick and easy comparisons across studies are possible and communication is more efficient.

There is nothing wrong with clarity or consistency. But to try to reach these ends by developing general procedures to gather data and universal methods to analyze and explain them can lead too easily to a reification of knowledge, an acceptance of knowledge as external and objective. How does this happen? As I read some of the articles on student misconceptions in biology, for example, I detect an implicit

"right answer/wrong answer" bias. Instead of representing student knowledge structures in an effort to learn how students are making sense, the focus switches to the representations of learners' knowledge, and these are compared to some "correct" representation. We may be more sophisticated and talk about degrees of rightness or wrongness, but knowledge once again, has been reified. Knowledge is a product that exists external to humans, and the processes of making sense are ignored, as are the people, as are conditions that could produce different views of subject matter concepts.

We must remember that when we develop representations of mental structures processes, we are only developing models. We are making metaphors - this person talks as if she were viewing heat in this fashion, this person reacts as though he were making this kind of mental transformation. If we forget the subjunctive, the metaphoric nature of our models, we may forget to be interested in the activities of people constructing and refining knowledge. This forgetfulness is all too common in educational research and curriculum development. An example can be found in many of the packages being sold that are designed to foster "critical thinking" or "higher order thinking skills." As Hultgren observed:

The more tightly we control our language and discourse about thinking in this way, the more severely we cover or suffocate what it is that we are seeking to illuminate. If we hand down these [thinking] skills from teachers to students, and then measure whether or not students have indeed learned these skills, what do we really come to understand about what thinking is like? (Hultgren, 1987, p. 3).

Given the tradition of research in which most of us were raised, it is not difficult to see how a search for products, for agreed upon universal procedures develops. It is, though, possible to communicate about our work in a way that

does not focus on outcome measures and does not forget the inherent ambiguity of all procedures. The discussion by David Cohen (1987) provides one model. His description lets us experience vicariously how his students used their concept maps to discuss their own thinking and understandings. Such research is more difficult to write because the description has to be rich and terms used have to be carefully explicated.

Analysis of classroom communications can provide another way for us to study learners in the process of learning. Lemke (undated) used "social semiotics" to study discourse in physics classrooms. A social semiotics assumes:

all meaning is made by specific human social practices. When we say that the mastery of physics or literary criticism is being able to talk physics like a physicist or write analyses like a critic, we are talking about making the meanings of physics or literary criticism using the resources of spoken and written language. Talking physics and writing criticism are social practices. (Lemke, undated, p.1)

In this paper Lemke uses the notions of *genre* and *semantic patterns* to analyze a brief teacher/student discussion in a physics class. His analysis is a powerful one for it allows us to see, not just the existence of but the perpetuation of a student misconception. Lemke teases out how the student fails to grasp a distinction made by the teacher and how the teacher, using the formal language of physics, does not detect his failure to make a distinction explicit in a way the student could grasp. Student and teacher used the same words but not the same meanings. The student's confusion continued.

Lemke's analyses are painstaking and time consuming. No one in the act of teaching could make such analysis. However, the analyses can alert us to the kinds of miscommunications that occur when a novice and expert talk

about subject matter and give us another way to look at student thinking in a discipline.

ENGAGEMENT WITH LIVED SITUATIONS: THE CONTEXTS OF LEARNING

In discussing teaching for conceptual change, Strike and Posner

see learning as a rational enterprise, and we understand rationality as having to do with the conditions under which a person is or should be willing to change his or her mind (Strike and Posner, 1985, p. 211).

The definition of and methods that then lead to the development of rationality have been of interest to many. MacMillan (1985) uses a broad definition of rationality and then argues that learning rationality begins with a process more akin to training than to education.

Rationality in teaching is possible only when there has already been a nonrational impartation or training in the procedures of rationality, as part of the more-or-less primitive language games and world-pictures inherited from the cultural and social context in which the individual has grown up" (MacMillan, 1985, p. 419).

Schools, however, do not always provide training in the procedures of rationality, nor settings which allow rationality. Many writers have looked at the political forces shaping schools, at the "hidden curriculum" and other ways schools serve to perpetuate existing social inequities. Britzman (1986) explicates how the compulsory nature of schooling creates antagonisms between teacher and student. These antagonisms produce a need for control, and teachers spend much of their energy exerting control. Many of the language patterns developed in the school serve to enforce control. Control language patterns are not those that characterize rational inquiry or discussion. The development of school language patterns whose purpose is control begins

early. Freebody and Baker (1985) examined the speech patterns presented in basal readers.

Finally, the representation of an orderly, centrally governed turn-taking system may be seen as a means of presenting the turn-taking system of classroom talk. The idealized versions of child-adult talk shown in the readers approximate the orderliness, formality, and centralized control of instructional, conversational routines known to characterize "teaching and learning" talk (Edwards, 1980, 1981; McHoul 1978; Mehan, 1979) more than they reflect the complexity, informality, and local management of everyday, conversational, multiparty talk (Freebody and Baker, 1985, p. 395).

If we fail to attend to the control mechanisms operating in schools, our efforts to use cognitive psychology to produce changes can only fail. In a 1986 address to the Ethnography in Education conference Susan Florio-Ruane described how a teacher subverted cognitively oriented scaffolding techniques (such as those described by Palincsar, 1986) for the teaching of writing. Techniques designed to facilitate writing as process were interpreted and applied in a way that maintained teacher control and so encouraged rote learning.

As we look for ways to increase comprehension and meaningful discussion, we must be aware that the meanings assigned to those strategies will be interpreted through a framework developed in formal schooling. If we are committed to improving learning, we must examine the taken-for-granted structures in schools and how they must be modified. We cannot be content with schools as they are, for their structures, internalized by actors within them, interfere with efforts to facilitate cognitive change and meaningful learning.

CARE AND SOLICITUDE: THE EMOTIONS

Much of the work in cognition assiduously avoids any consideration of emotion, or as educational jargon would have it, the affective domain. To make such a separation not only eviscerates the conception of a human but also leads to inaccurate results of experimentation in cognition. Leslie Hart (1976) explicated nicely a mechanism that accounts for the complex relationship between emotion and cognition. His model makes sense of the findings that demonstrate how emotions strongly influence cognition.

In school classrooms in which the teacher's practices instantiate the control functions of schooling and the implicit hierarchial organization of people and knowledge, knowledge becomes power, wielded by those who have it over those who do not. However subtly control operates, the emotional climate generated is one of domination and fear, rather than care and solicitude. The thinking of individuals will be constricted, as will the social interactions necessary for rational discussion. In such settings, students can play it safe, follow the rules, and passively memorize to pass the tests. Or, students can resist and refuse to memorize. In either case, knowledge remains external, no new meanings are generated and students will remain uninvolved.

Those of us who want to change what goes on in schools need to surface the assumptions that lead to this emotional state. We need to sense the feelings that lead students to respond in "safe" ways. We need to examine our own practices to make visible the assumptions we have about teaching/learning that have too much to do with control and too little to do with learning. Until we look at and amend our own practices, we cannot hope to provide the sanctuary within which rational discourse can occur and deeper understandings can develop. We must learn to work with people before we can work with cognition. If we cannot create the emotional climates necessary for communication -

thinking and speaking - all our cognitively oriented work will be wasted.

CONCLUSION

Are these dangers inevitable? Will work on human cognition develop into one more search for angels dancing on pinheads? Not necessarily, but I think we have to examine our practices most carefully. West and Pines mention that the use of qualitative research methods has contributed greatly to the growth of cognitive psychology. We must make sure that we are really using new perspectives and not trying to fit "qualitative" data into former scientific molds. We must practice ways of doing and communicating about research that are rigorous and systematic but do not mirror the dangers we have seen in thoughtlessly applied quantitative methods.

We must make our research reports richer and broader. It is not enough to describe differing ways students conceive of a subject. We must attempt to describe the processes and contextual factors that contributed to those understandings and document other ways of teaching/learning to avoid or ameliorate the problems. We must work to produce the contexts needed to foster the thinking of people as they attempt to live richly. We have to try things out and document our trials, sharing with each other. We must become story tellers, able to tell our stories without bias but with the richness that will allow others to share our work with people struggling with real issues.

REFERENCES

- Britzman, D.P. (1986). Cultural myths in the making of a teacher: Biography and social structure in teacher education. Harvard Education Review, 56(4), 442-456.
- Cohen, D. (1987). The use of concept maps to represent unique thought processes: Toward more meaningful

learning. Journal of Curriculum and Supervision, 2(3), 285-289.

- Freebody, P. and Baker, C.D. (1985). Children's first schoolbooks: Introductions to the culture of literacy. Harvard Educational Review, 55(4), 381-398.
- Gardner, H. (1985). The mind's new science. New York: Basic Books, Inc.
- Greene, M. (1987). The essence of artistry: Making the process visible. Paper presented at the annual meeting of the American Educational Research Association, Washington, D.C.
- Greer, R.D. (1983). Contingencies of the science and technology of teaching and prebehavioristic research practices in education. Educational Researcher, 12, 3-9.
- Hart, L.A. (1978). How the brain works. New York: Basic Books.
- Hultgren, F.H. (1987). What does it mean to experience critical thinking? An interpretive-critical perspective. Paper presented at the annual meeting of the American Educational Research Association, Washington, D.C.
- Lemke, J.L. (undated). Genres, semantics, and classroom education. Linguistics and Education, forthcoming.
- MacMillan, C.J.B. (1985). Rational teaching. Teachers' College Record, 86(3), 411-422.
- Palincsar, A. (1986). The role of dialogue in providing scaffolded instruction. Educational Psychologist, 21, 73-98.
- Schoen, D.A. (1983). The reflective practitioner. New York: Basic Books.
- Strike, K.A. and Posner, G.J. (1985) A conceptual change view of learning and understanding. In Cognitive structure and conceptual change. L.H.T. West, and A.L. Pines, (Eds.). New York: Academic Press.

West, L.H.T. and Pines, A.L. (Eds.) (1985). Cognitive
structure and conceptual change. New York: Academic
Press.

SCIENCE FOR THE NON-SCIENCE MAJOR

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Concerns regarding the quality of science education in Canada have recently been expressed by the Science Council of Canada in the document, "Science for Every Student" (1). In this document, the Council states that 'Canada needs all its citizens to be scientifically literate', and to this end, supports a concept of scientific literacy as a guide for the development of science programs. As well, the Science Teachers' Association of Ontario (STAO) has recently declared that 'scientific literacy should be the principal purpose of science education in every curricular division' (2).

To most people, literacy means an ability to read and to write; skills that are easy to acquire and measure, and that can be improved upon with practice and experience. Furthermore, possession of these skills does not specify what it is to be read or written. When the word, 'literacy' is prefaced by 'scientific', however, it is often assumed that the skills of reading and writing are merely being channelled to the reading and to the writing of science. Such an interpretation is naive and incorrect, for it does not reveal the competencies that the scientifically literate person is expected to possess, and therefore does not reveal the skills, knowledge, and attitudes which the teacher of

science strives to develop in the learner. Given the cryptic nature of this term, it is not surprising that different interpretations will exist, and that confusion can often result whenever a dialogue on this topic is held. In the absence of any explicit definition for the concept of scientific literacy, it is important that those using the phrase, define it.

The Science Teachers' Association of Ontario which, as stated earlier, promotes scientific literacy as the principal purpose of science education, has indeed, provided its concept of scientific literacy in its recent curriculum policy paper (2). It does so by identifying those abilities which it expects the scientifically literate person to be able to demonstrate. These are:

1. the ability to understand and to be able to apply scientific thinking - process skills and problem-solving,
2. the ability to apply scientific knowledge to daily living,
3. the ability to recognize that science is a discipline with an ever-expanding body of knowledge,
4. the ability to understand the application of science to technology,
5. the ability to apply scientific knowledge to the decision-making process,

6. the ability to understand the development of science in an historical context,
7. the ability to have a feeling of self-worth and 'fate-control' as a result of an adequate knowledge base and problem-solving skills.

Certainly the above list recognizes valuable qualities for people to have in our society today. It also presents significant challenges to teachers of science, both in regards to teaching effectively towards these goals, and designing the appropriate instruments to determine the extent to which these objectives are being achieved.

It is important to note that the above list of abilities does not include any reference to a specific body of knowledge. For example, there is no statement that suggests that scientific literacy must include, 'the ability to comprehend those basic concepts inherent to the various disciplines that comprise the physical and life sciences'. Presumably, therefore, the choice of subject matter is clearly secondary to the more important objectives associated with scientific literacy. A well-planned and well-taught course in any science should be able to contribute significantly to the development of scientific literacy, without having to 'expose' the learner to a vast array of subject matter from a number of scientific disciplines.

Most often, however, scientific literacy is not the only objective of a science course. In fact, concern for presenting the basic concepts of one's discipline, for

providing career preparation, and for 'covering' topics deemed to be prerequisite for more advanced courses, are concerns likely to diminish, significantly, the attention which scientific literacy receives. The objective of scientific literacy will be further compromised in courses having an excessive knowledge content, and staffed by instructors who perceive a strong association between scientific literacy and the acquisition of an extensive and specific body of knowledge.

Like many colleges and universities, Brock University requires all of its students to complete a science requirement in their undergraduate program. The rationale for this requirement, as initially stated in 1969, was, "to permit the students to investigate the principles by which the physical (including biological) world operates, in order to understand the present technical basis of our civilization." The above statement has not been revised since and remains obscure within the university, even to those involved in teaching the sciences. Nevertheless, the regulation remains and all students must enrol in at least one science course.

To satisfy the science requirement, students may enrol in science courses that are part of the science programs, or they may select one of the science courses designed especially for non-science majors. Non-science students usually choose one of the five science courses designed for them by the Departments of Physics (astronomy), Chemistry,

Biology, Geology, and Geography. Not only can these courses for non-science majors be as intellectually stimulating and demanding as the 'regular' science courses, but they can also provide ideal environments for focusing on scientific literacy. It is in such courses that this objective can be established and maintained as the primary one.

The course which the biology department offers to the non-science majors carries the title, "Biology, Man and Environment" (Biology 125); a title that is broad enough to accommodate virtually any biological theme. Since 1984, the enrolment in this course has surpassed 700 students per year. To accommodate this number, two lecture sections are offered, as well as 30 laboratory-seminar sections. This 26-week course consists of two lecture hours per week, as well as eight laboratory and two seminar sessions.

Predictably, the students in such a course constitute a diverse group in regards to experience in science, and motivation and attitudes towards science. There are students in the course sufficiently qualified to be science majors; there are others who abandoned science after grade nine in high school. Some of the students have confidence in their abilities to comprehend and succeed in science; others will enter with little confidence and with considerable anxiety. There will be those who accept the science requirement willingly, and with the expectation of a valuable learning experience; others will view the requirement as a necessary evil to be accommodated with a minimum

of effort. It is a significant challenge to develop a course that accommodates this diversity of students, for one must challenge the experienced science students without intimidating or discouraging those who are less prepared. And, of course, one wants the course to be viewed by all students as a worthwhile experience, and one likely to have considerable long-term value.

With few exceptions, the non-science majors in this course are enrolling in their final science course. It becomes important, therefore, to clearly determine the knowledge, skills, and attitudes that one should attempt to develop in these students. Or if expressed in the context of 'scientific literacy', one needs to decide which of the competencies associated with scientific literacy should be developed in these students. Certainly the acquisition of a specific body of knowledge or skills for vocational needs, or as a prerequisite for further courses, is not important for these students; the development of scientific literacy is, however.

As defined by STAO, and presented earlier, scientific literacy incorporates a number of abilities and insights. Since it is difficult to address all of these adequately in any single science course, a more realistic strategy is to select a limited number of objectives upon which to focus. The three objectives which constitute my preference are briefly identified below.

Objective #1: To have the students recognize that 'science' is but another way of knowing and that knowledge claims are constructed on the basis of information gathered by a variety of modes of enquiry. As a consequence, students should recognize that such knowledge claims will inevitably be limited by the quality of information available and by the intellectual resources of the investigators, and will be constrained by the paradigms in which the investigations are being conducted. Such knowledge, therefore, will be vulnerable to modification or rejection on the basis of new information, more novel interpretations, or competing knowledge claims.

Objective #2: To have the students examine, in depth, a few topics that hopefully they will perceive as being important and personally relevant. There is no intent to indoctrinate the students, however, it is intended that such intensive studies will challenge the students to reflect on some of their attitudes, and behaviours. For example, a unit on cardiovascular physiology, aerobic fitness, and heart disease, should challenge the students to reflect upon their own level of participation in aerobic activities. The unit on the biology of cancer does provoke the students to re-examine their lifestyle choices in regards to risk factors.

Objective #3: To develop a positive attitude towards the learning of science so that the students will want to read, to listen to, or to view, some contemporary issues having a science component; issues that are communicated through newspapers and magazines, and through radio and television.

The three objectives identified above, focus on process, issues and attitudes. These objectives are important components of scientific literacy and are especially challenging to pursue with students who are not science majors. Below is an elaboration of these objectives.

I. PROCESS: If students are to recognize that knowledge claims made in science are dependent upon, and derived from observation, measurement, and data analysis, then the students should routinely experience opportunities to observe and to assess data, and to construct and evaluate explanations. This requires, of course, that the students are made aware of the experimental protocol from which the data is obtained. In fact, as the course progresses, one can expect them to become more experienced, and often more sophisticated, in assessing the methodology of those investigations selected for study and analysis.

To emphasize the empirical nature of science, I favour describing experimental investigations and presenting data in my lectures. For example, a six-week unit on cardiovascular physiology and fitness was initiated by describing

some studies in which the investigators focused on some of the dimensions of the heart, especially thickness and mass of the left ventricular wall, and the internal dimensions and volumes of the chambers. After briefly describing the structure of the heart, the technique of echocardiography, and the methodologies of the studies, the dimensions could then be presented. In some of the studies, data were presented for groups of runners, swimmers, cyclists, weight-lifters and wrestlers, as well as for age-matched, non-athletes. In another study, various dimensions of the heart were presented for a group of males, both before and after a well-defined training program. As the dimensions, as well as sample size and standard deviations, are being presented in tabular form, it soon becomes apparent to the students that large differences exist between the various athletic groups. The aerobic athletes have larger left ventricular volumes and the power athletes have thicker walls. The students are also able to use the data from some of the studies to suggest that the differences have resulted from specific training protocols, rather than from inherent differences that preselect individuals into specific sports. The use of such studies allows the students to make some knowledge claims, and to attempt to provide some explanations for the differences that are observed. It also elicits uncertainties regarding the experimental protocol, and provides a basis for discussing the design of investigations that would clarify these uncertainties. Even in a

lecture hall with 400 students, an instructor with a portable microphone can elicit student involvement with the data being presented.

It is important, of course, to begin with studies that are easy to comprehend. These studies should provide data which permits observations to be recognized quickly, and for which explanations can be easily constructed. More sophisticated and difficult studies can be expected to follow. In the unit on cardiovascular fitness, the initial studies that focus on the dimensions of the heart, are followed by investigations that look at arterial diameters, blood pressure measurements, blood lipoprotein concentrations and glucose tolerance and insulin sensitivity, in various athletic groups, both young and older, and in age-matched, non-athletic groups. Of course, each of the above topics requires the presentation of some descriptive biology, but such information is given only to an extent that it enables students to understand the research investigations that are to be examined. The emphasis remains on the presentation of data, on means and sample sizes, and on differences that are statistically significant. Students will repeatedly be encouraged to look for valid control populations, to identify the controlled and uncontrolled variables, to assess the experimental design, and most importantly, to construct knowledge claims and explanations.

In addition to the immediate outcomes that the presentation and analysis of empirical studies provide, important

principles relating to science generally, and to biology specifically, will also emerge as the course progresses. These principles are brought to the attention of the students at appropriate times throughout the course. Some of the principles arising from the unit on cardiovascular physiology are as follows:

1. Biological systems are highly structured systems, and measurements of structural organization or functional processes provide numerical values that are not random, but which show a pattern of distribution within identifiable limits.
2. Structural and functional properties of biological systems can be modified in response to perturbations or repeated stress. Furthermore, when differences in structure or function are observed between 'apparently' similar populations, explanations can be constructed to account for the differences.
3. The knowledge claims and explanations that are made regarding natural phenomena must be subjected to verification. Furthermore, in response to the development of new investigative methodologies, to an expanding body of information, and to innovative thinking, one can expect knowledge claims and explanations to be constantly reviewed, and to be modified or rejected, as necessary. Consequently, statements claiming 'proof', 'truth' or 'certainty' must be viewed cautiously. If knowledge claims in science are indeed constructed, then reference to the 'discovery' of

scientific knowledge becomes more difficult to justify.

4. One's confidence in observations and explanations will increase when the supportive information can be verified and when large sample sizes are involved. Anecdotal experiences, though often important for suggesting further investigations, are not the experiences that can be defended strongly and with confidence.
5. Not all the information obtained in science must come from 'experiments' performed in the laboratory or in the environment. In fact, significant knowledge claims can arise from epidemiological strategies and from the non-manipulative observation of natural phenomena.

Scientific news communicated to the public through the various media is often difficult to evaluate, especially when the source of the information and a description of the investigations are not provided. The situation is especially difficult when conflicting information is at hand, as is often the case when one is dealing with such issues as environmental quality, the identification of health risk factors, safe food choices, and strategies for health promotion. A science course in which the students regularly evaluate methodologies, results, interpretations and knowledge claims, should be providing valuable tools for critically evaluating scientific news as it is presented through the various communications media.

II. ISSUES. The use of empirical studies to examine selected structural and functional aspects of the cardiovascular system is not the primary focus of the unit. In fact, these studies are used to eventually develop the concept that biological organizations are responsive to stimuli and that adaptations, both structural and functional, can result from the repeated exposure to stress. In this unit, physical activity serves as the stress.

Even the development of this important concept, however, is not the primary purpose of the unit. Subsequent lectures focus on cardiovascular disease, risk factors associated with this disease, and some of the mechanisms by which exercise might modify these factors. Ultimately, data from some recent studies relating physical activity, heart disease, and longevity are presented in lecture, and further discussed by the students in seminar. The focus on lifestyle choices, health, and longevity, provides an opportunity to address some interesting and provocative contemporary issues, and gives the entire unit on cardiovascular physiology a relevance to many of the students.

There is, of course, no shortage of topics or issues available for development within a biology course. Last year, in addition to the unit on cardiovascular physiology, the topics of cancer induction, animal and human aggression, and nuclear winter, were also investigated. In previous years, issues related to human social behaviour, immunology, sexually-transmitted diseases, ionizing radiation, global

population growth, agricultural productivity, and habitat destruction, have also been addressed. Despite the large number of topics available, one must recognize that the issues that emerge from these topics are value-laden, and may not be those that are highly valued by all the students. Students who value personal wellness and who are therefore receptive to such topics as physical activity, nutrition, and cancer, may not be especially receptive to such topics as acid rain, nuclear winter, or global population growth, where environmental quality and the needs of future generations are valued.

III. ATTITUDES. If the 'scientifically literate' person is expected to apply scientific knowledge to daily living, to apply scientific knowledge to the decision-making process, and to maintain a feeling of self-worth and fate-control, then one would expect such a person to maintain an interest in some issues having a scientific component and, on occasion, to explore new ones. Certainly the individual must not be intimidated by the jargon of science or by its perceived complexity. Furthermore, confidence in one's ability to study and to learn science is likely to be an outcome of learning experiences in science that are favourable, and successful in regards to attaining acceptable grades.

To foster successful learning experiences and to reward students fairly, does not imply that topics in the course must be dealt with superficially, or that high grades must

be awarded too generously. It is likely to require, however, instructors who are imaginative and well-organized, enthusiastic and encouraging. They will be sensitive to the difficulties likely to be experienced by the learners, and will be truly concerned with having the students attain the goals upon which the course is focused. Instructors pre-occupied with 'covering' an excessive amount of material at an unnecessarily difficult level of comprehension, are likely to create confusion, disinterest, and despair on the part of the students, and an unfavourable grade distribution as well! Most sadly, however, a valuable opportunity to promote scientific literacy will have been squandered.

Discussion of the primary objectives of a course for non-science majors is a relatively easy task. It is more difficult to provide evidence that the objectives are, in fact, being met. Nevertheless, some indicators are available. For example, it was stated earlier that students should, with reasonable effort, be able to experience success in such a course. In fact, the failure rate in the biology course I have been describing has ranged between 2.7% and 6.5% during the past four years, with a mean of 4.1%, and with class averages ranging between 62 and 67%. Such failure rates are considerably lower than the rates that characterize the 'normal' first year science courses. Nevertheless, a final grade above 70% still represents a significant challenge, since only about 20% of the students are able to attain this grade level.

Consistent with the objectives of the course, is the fact that the course is rated highly by the students, and that some acknowledge changes in behavioural patterns, especially in regards to smoking and exercise, and in their attitudes towards science. It is also encouraging when students choose, as a result of this biology course, to enrol in another. In this year's first year biology course for majors, 21 of the 133 students had, in fact, previously completed the biology course for non-science majors.

Although the midterm and final examinations in the course are multiple choice in format, these exams represent a valuable opportunity to re-enforce some of the important objectives of the course. Specifically, the exams are used to have the students read science, study empirical data, and evaluate knowledge claims from information presented on the final examination; information the students have not seen before. One of the formats commonly used is to present to the students recently published news articles that relate to some of the major themes in the course. The students' comprehension, and possibly assessment, of the information can then be ascertained through the use of multiple choice questions. The second format involves presenting results from articles that have recently been published in scientific journals. Often, some of the methodology must also be included to provide the student with a better understanding of the source for the data. From analysis of the data, students can be challenged, again through the use of

multiple selections, to identify important observations and relationships, and to assess claims that the data might support. Of course, the final examination will also test the student's knowledge and understanding of the lecture, laboratory and seminar components of the entire course.

On ten occasions, students experience a two-hour laboratory or seminar session. These occur biweekly and extend over both terms of the course. Although limited in duration, and neither technologically or scientifically sophisticated, the eight labs are still a valuable component of the course and foster some of the objectives previously described. They emphasize the importance of observation and detail, and focus on information that the students find interesting and recognize as significant. The labs provide a pleasant and novel learning environment, and also provide a means whereby a reasonable student effort can be favourably rewarded with marks. Three of the laboratory sessions involve the use of dissected fetal pigs to study various organs and organ systems, and four of the sessions utilize the compound microscope to observe chromosomal changes during cell division and gametogenesis, human blood cells, and the structure of normal and cancerous human tissues. One laboratory session focuses on the structure and replication of DNA, and on the events associated with protein synthesis. For many students, the experiences of studying dissected fetal pigs and of utilizing a compound microscope, are novel ones.

During the laboratory sessions, students are assisted by two demonstrators, and guided by a lab manual containing worksheets to be completed by the students as they work through the laboratory protocol. These worksheets are submitted at the end of the two-hour period for evaluation, and no further assignments are required from the students. Although the lab sessions function independently of the lectures, the information and experiences in the labs frequently complement the topics in the lectures. Many biological structures observed and drawn during the sessions with the fetal pigs, are referred to in the units involving human physiology and cancer, and the information acquired in the labs involving the structure and function of hereditary material certainly complements the topics of cell division, gene expression, and mutagenesis, which are important to the unit on cancer.

The two seminar sessions provide opportunities for the students, assembled in their normal laboratory groups, to discuss some of the relevant issues raised in the lectures. For example, a seminar period was organized to focus on E. O. Wilson's book, "On Human Nature", following a series of lectures on the genetic basis of human social behaviour. Last year, the seminars focused on 'nuclear winter', and 'public health policy in regards to exercise behaviour'. In preparation for the seminars, students are required to complete a reading assignment and to reflect on a series of questions that identify the substantive issues likely to be

addressed during the seminar discussions. Although some students enjoy participating in seminars and contribute to making the seminar a lively forum for discussion, there are, unfortunately, other students who are hesitant to express themselves in small discussion groups. For these students, the seminar can represent a very stressful environment. Nevertheless, the seminars are considered to be an essential component of the course and therefore the seminar leaders are constantly challenged to achieve a discussion that encourages participation and which addresses the issues in thoughtful and meaningful ways.

Colleges and universities that require non-science majors to complete at least one course in science inevitably create a population of reluctant science learners, and in some cases, even hostile ones. Nevertheless, the requirement can be justified, and in this paper, it has been defended in terms of the need for increased scientific literacy. The primary purpose of this paper, however, has not been to defend the importance of scientific literacy, but to describe the structure of a biology course which has as its objectives, some very specific aspects of scientific literacy. It is a biology course that has been developed in an educational environment that provides one the freedom to define course goals, to establish course content and instructional strategies, and to choose the means by which students are to be evaluated. It is also a favourable environment in regards to material and human resources.

Under these conditions, teaching science to the non-science major becomes an exciting challenge, with the potential for considerable personal satisfaction and success.

1. Science for Every Student: Educating Canadians for Tomorrow's World. 1984. Report 36, Science Council of Canada, Ottawa.
2. A Rationale for Quality Science Education in the Schools of Ontario. May, 1985. Science policy paper, Science Teachers' Association of Ontario.

Drawing Concept Circles:

A Way of Revealing What the Learner Knows

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Concepts give our world stability. A concept is a regularity in objects or events designated by a language (or symbol) label. People use concepts both to provide a taxonomy of objects or events in the world and to formulate relationships between concepts in that taxonomy. "Without concepts, mental life would be chaotic" (Smith & Medin, 1981).

"A central challenge and dilemma of teaching is to provide students with the intellectual blueprints for assembling a conceptual edifice whose form cannot truly be known until all the forthcoming separate bits of knowledge are in place" (Toth, 1980). Diagrams can play a vital role in facilitating the process of reassembly. Winn (1981) has found that diagrams have two properties important to science education. Diagrams can show realistic representations of concepts and they can show the relationships between concepts. By definition, a diagram is a line drawing that explains something by showing arrangement and relationship of parts.

The ancient Egyptians may have been the first to represent ideas with drawings. Their hieroglyphic writing system arranged symbolic engravings to express important concepts (Silano, 1958). Other cultures used similar methods; Aztecs and early American Indians, for example, conveyed messages by pictographs.

"The writing of most primitive peoples goes through the ideographic, syllabic, and alphabetical stages" (McDonald, 1958). Usually the first two forms of writing were discarded after alphabetical symbols had been formulated. The Egyptians were an exception to that rule--they continued to use pictorial (ideographic) writing for 3,500 years even though they also used the two other forms. Could it be that this

important ancient civilization found it to be superior for communicating ideas? Because diagrammatic writing operates at a lower level of abstraction, might it have been a more effective (albeit less efficient) way of representing concepts than using words?

Briggs (1984), in summarizing what is known about the mind of a genius, points out that most geniuses regularly use images of wide scope in order to see the relationship between pieces of information in new and unusual ways. Einstein, for example, was educated in a school run by principles of the educational reformer Heinrich Pestalozzi, who stressed the development of visual imagination. "Einstein later insisted that his best ideas always came to him in the form of visual images, the mathematical and verbal expressions followed months or years later" (March, 1978).

Kekulé dreamed of a snake biting its own tail and used that image to construct his benzene ring. Snow employed a map of London to solve the mystery of how cholera was transmitted (Judson, 1980). Mendeleev made a deck of chemical element cards which he fastened to a wall in various patterns to help him devise his periodic table of the elements. The history of science is replete with examples of how diagrams were used to solve important intellectual problems.

James L. Adams (1979), who teaches engineers at Stanford, has found that his verbally and mathematically talented students are "visual illiterates" who can benefit greatly from exercises that develop their visual thinking ability. He calls it an "alternate thinking language" and considers it "one of the most basic of all thinking modes and one that is invaluable in problem solving" (Adams, 1979).

Diagrammatic Techniques in Modern Science Education

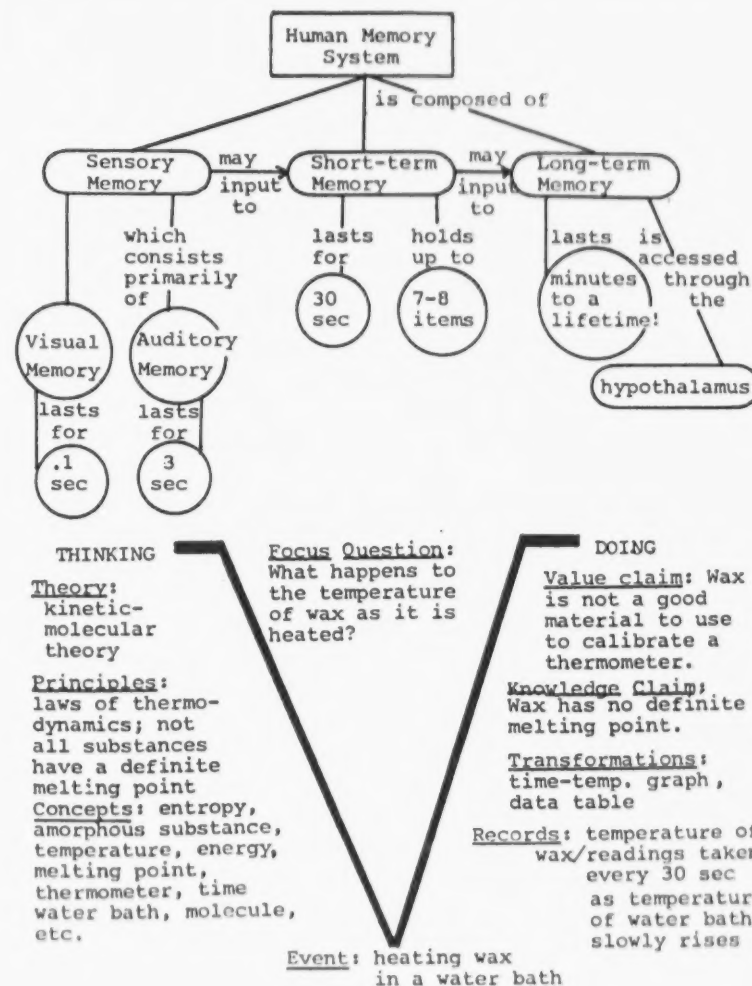
Today, science educators make use of a variety of diagrams to help students grasp important concepts. For example, Punnett squares are used in genetics, ray diagrams in optics, schematic diagrams in electronics, and weather

maps in meteorology. Such visual tools are subject-specific.

In contrast, concept maps and knowledge vee diagrams are powerful metacognitive tools with broader applications in science teaching (Arnaudin, Mintzes, Dunn, & Shafer, 1984; Novak, 1981; Novak, Gowin, & Johansen, 1983). Gowin's knowledge vee helps students understand the nature of knowledge and how it is produced. Concept maps help the learner produce a visual representation of the hierarchical relationship between concepts. A thorough treatment of both techniques may be found in *Learning How to Learn* (Novak & Gowin, 1984). Both tools are soundly based on Ausubelian learning theory and constructivist epistemology. Concept maps and vee diagrams are diagrammatic representations of concepts and conceptual structure--both are strikingly visual techniques. It is difficult to imagine two teaching tools with broader application to the modern science classroom than these. (See Figure 1. for examples of each tool.)

After seven summers of post-doctoral work in science education at Cornell University studying the learning theory of David Ausubel and after seven years of experience using concept mapping and vee diagramming to teach college science, I concluded that a third, theory-based, metacognitive tool might be helpful in visualizing the concepts college students hold. Dunn (1983), in her innovative "mib" study of concept learning, observed that "most science concepts derive their meaning from the systematic relationships in hierarchical knowledge or from the inclusive-exclusive relationships in taxonomies." Although concept mapping can perform both functions, the latter function is less visually effective, I contend, than the technique proposed in this paper. In addition, students who have difficulty beginning their study of metalearning with concept maps can start by drawing concept circles. Novak and Gowin (1984) point out that "Approximately 5 to 20 percent of students respond negatively to instruction that requires meaningful learning. These students will resent requirements for concept mapping and

Figure 1. Examples of a concept map and a vee diagram



vee diagramming." It is my hope that the technique of drawing concept circles might introduce students to metalearning in a simpler way, so that when they are taught to use concept maps and vee diagrams, they will experience a more gradual increase in the level of difficulty. Novak (1977) postulates that "the emotional experience is most likely to be positive when instruction is planned to optimize cognitive learning." In other words, we are most likely to enjoy what we are most successful at learning to do.

An Old Tool with a New Use

To meet theoretical and practical needs, the heuristic device used to represent inclusive-exclusive relationships between concepts must be: (a) visually effective, (b) conceptually effective, (c) apply Ausubel's theory of learning in its design, and (d) serve as both an instructional and a diagnostic metacognitive tool.

Logicians will recognize the device I have chosen. Venn (1894) points out the fact that logicians borrowed the use of diagrams from mathematics during the time when there was no clear boundary line between the two fields. Line segments, triangles, circles, ellipses, and rectangles were all used to diagram categorical propositions during the early development of logic as a discipline (Venn, 1894).

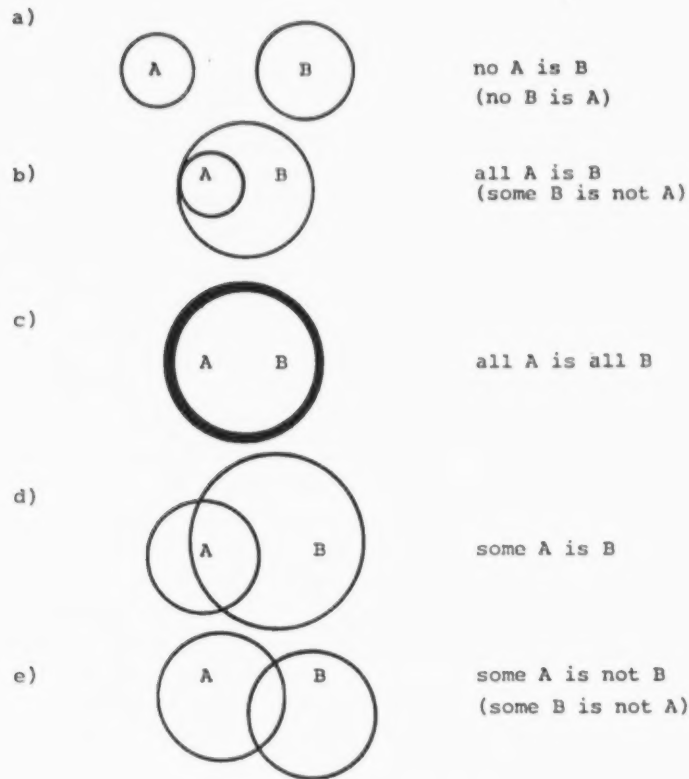
Although Venn diagrams are schematic representations of sets which were introduced by John Venn in 1880, I have not selected them for the task at hand because they are primarily intended to illustrate set theory operations such as union, intersection, and complementation (Arnold, 1983; Parker, 1984). Some science educators have used them. Leisten (1970) proposed using Venn diagrams to show students the relations between chemical terms. Gunstone and White (1986) showed that Venn diagrams can be used to teach physics and to probe students' understanding of physics concepts. While Leisten did not use the language of sets, the students in the Gunstone and White study were already familiar with set theory.

Since Venn diagrams typically are used to represent categorical propositions or syllogisms, special shading and starring processes are used and the number of circles in a diagram is limited to three. Venn suggested that for inferences involving more than three classes, ellipses or more complicated shapes other than circles should be used. Since I wanted a diagram that used circles and could represent up to five concepts, the average capacity of short term memory (Miller, 1956), I did not adopt Venn's system of diagramming for this task.

The concept of logic diagrams was already in use during the Middle Ages (Gastev, 1977). In fact, the ancient commentators of Aristotle represented the modes of syllogisms by using geometric drawings (Kuzicheva & Novoselov, 1977). The use of circle diagrams was already known to J.K. Sturm in 1661 and the first systematic application of circle diagrams seems to be in a treatise published by Johann Christian Lange in 1712. Dimitriu (1977) notes "The representation of judgments and of the relations expressed by them is generally attributed to Euler." The device he invented is called "Euler's Circles." It is Euler's diagrammatic method which I have adapted as a metacognitive tool. Leonhard Euler (1707-1783) was a Swiss mathematician who was "one of the greatest mathematicians of all times; he made important contributions to practically every area of pure and applied mathematics" (Kuzicheva & Novoselov, 1977). By 1978, a modern edition of Euler's works filled 71 volumes of a projected 74-volume collection (Duffety, 1980).

Although he wrote on so many subjects, of particular interest here is his way of representing class relationships using circle diagrams. His diagrams can demonstrate: (a) class exclusion, (b) class inclusion, (c) class equality, (d) class product, and (e) class sum (Reese, 1980). In order to illustrate his ideas, Figure 2. has been included.

Figure 2. Examples of Euler's Circles



Note: Darker line shows superimposition of circles.

A detailed and substantiated formulation of logic diagrams was first given by Euler in 1768 in his Lettres à une princesse d'Allemagne, in which he examined what are now called Euler's circles. Martin Gardner (1968) suggests that Euler's circles were eventually replaced by Venn's diagrams because Venn's system fit Boolean class algebra so well. Many of the diagrams in books that are called Venn diagrams are actually Euler circle diagrams or modifications of them. For example, Kaplan (1983) uses many included and sometimes overlapping circles to represent trophic levels within an ecological community. Although he doesn't refer to Venn or Euler, the diagrams are Euler circles. They lack the format, shading, and notation characteristic of Venn diagrams.

Concept Circle Diagrams

Concept circles may be defined as two dimensional geometric figures (circles) that are isomorphic with the conceptual structure of a particular piece of knowledge and are accompanied by concept labels. Based upon Miller's (1956) work in information processing and Gunstone and White's (1986) view that Venn diagram tasks work best when they involve from two to five terms, no more than five circles are permitted in a concept circle diagram. Another reason for limiting the number of circles per diagram to five is the principle of visual perception which says that excessive detail on a diagram reduces its effectiveness (Reynolds & Simmonds, 1981).

Circles seem preferable to other geometric figures because they are easy to draw using a compass or template. In addition, the field of vision of both eyes is approximately circular (Van Amerongen, 1979) making the information in the diagrams easier to process. A drawn circle is also a good representation of a concept for another reason--any such circle is only an approximation of an ideal circle, every point of which would be equidistant from the center. To the extent that a concept is stable within and across individuals,

it is a bounded unit of knowledge. However, more and more modern theorists hold a probabilistic view of the concept which tests instances of a concept using a weighted sum of features. Since category membership can be achieved by various combinations of features, various feature-sets define acceptable instances of a concept and therefore concepts have somewhat "fuzzy" boundaries (Smith & Medin, 1981).

In contrast to standard Venn diagrams, the concept circle technique makes use of direct labeling for each circle instead of coding. This avoids "double scanning" from diagram to key and makes the graphic more visually efficient. For ease of reading, concept labels are printed in lower case (Reynolds & Simmonds, 1981).

When a concept circle is constructed, quantitative and categorical (concept) information is encoded by labels, geometry, and color. Color is an important feature of a concept circle diagram since it helps the viewer distinguish between the elements of the diagram. Color hue and saturation are two of ten elementary graphical perception tasks we perform in decoding information encoded in a diagram (Cleveland, 1985). Although about ten million color differences can be detected by the human eye, our color memory allows us to remember only about 24 saturated hues (shades) of color (Levy, 1987). Yet that palette of colors may be very helpful in aiding understanding and recall by the learner, two important criteria for any metacognitive tool (Stuart, 1985). Dooley and Harkins (1970) showed that colored posters attracted more attention and Dwyer (1976) found that line diagrams in color were the most effective kind of illustration in a text dealing with the functioning of the heart. Reynolds and Simmonds (1981) observe that students distinctly prefer colored illustrations over black and white.

The area of each concept circle may be used to represent qualitative or quantitative differences between concepts.

Since Hailstone (1973) has suggested that charts which depend on proportional area to denote quantity may not be wholly satisfactory as many people are better at making comparisons on a linear basis, the standard sizes of circles to be used by students were determined experimentally. Since Stevens' Power Law describes the bias in area judgments, it was used to compensate for viewer decoding error (1975). Simply put, it says that the actual scale to a power equals the perceived scale. The value of the exponent, called the beta value, varies with the task.

Twenty-six students in college botany were given a test in which they had to choose four circles from a larger assortment that appeared to be 2, 3, 4 and 5 times larger than a 1-inch diameter referent circle. Beta values were computed from the results of each discrimination task and average beta values were used to calculate the sizes of a set of five circles that were perceived to be 2, 3, 4, and 5 times larger than the referent circle. This was used to make cardboard concept circle templates which students could use to draw concept circles in which the relative area encoded quantitative information. The sizes of the circles as determined by experiment were: 1", 1 7/8", 2 1/8", 2 1/2", and 3 1/8" in diameter.

According to Holliday, "students tend to remember science ideas longer when teachers use visual and verbal messages together" (1980). For this reason, students are asked to give each diagram a title and to write an explanatory sentence under their diagram. "Writing is a symbolic activity of meaning-making" (Howard & Barton, 1986). The word symbol, as used here, means anything that carries meaning--language, maps, diagrams, etc. Howard and Barton (1986) suggest that we combine writing with diagrams to capture our thoughts and speculate that "we grasp what our grasp of symbols enables us to grasp." In the ancient trivium, logic, grammar and rhetoric were the three subjects considered basic to all learning; here,

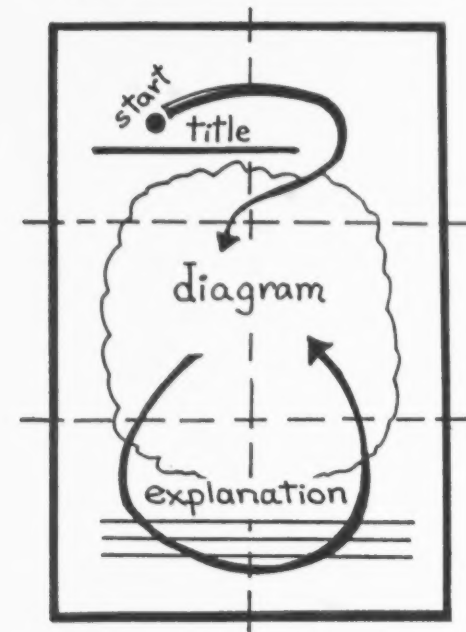
reasoning, writing and (graphic) expression are united to construct a concept circle diagram. The title is to be written in the top left sector of the page because "in most western cultures the observer's eye starts scanning a page from a point in the top left sector. A sweeping search of the page is then made, finishing where the main action is expected to be" (Reynolds & Simmonds, 1981). Diagrams which oppose the natural scanning pattern of the eye take more time for the viewer to interpret and are sometimes confusing. Figure 3. shows the eye's scanning pattern superimposed on the concept circle diagram format. It demonstrates that the format follows the eye's scanning pattern in a sequence that enhances understanding: title, diagram, explanatory sentence, review of diagram.

The Relationship between Concept Circle Diagrams and Ausubelian Learning Theory

In order to learn meaningfully, students must choose to relate new concepts and propositions to those they already know. With concepts represented by circles and relationships between concepts represented by spatial configuration of the concept circles, the learner has a way of revealing what she/he knows about a particular piece of knowledge. The diagram has concept labels, a title, and an explanatory sentence to assist the learner in understanding and recalling a particular piece of knowledge. The same attributes make the concept circle diagram a diagnostic tool for the teacher or educational researcher who wants to probe the learner's cognitive structure. Ausubel has said that the teacher needs to ascertain what the learner already knows and follow up with instruction appropriate for that individual.

In addition to the above characteristics, Ausubel's concepts of subsumption, hierarchy, progressive differentiation, and superordinate learning can be demonstrated with concept circle diagrams. As with concept maps and vee

Figure 3. The Scanning Pattern of the Human Eye in Relation to the Format of a Concept Circle Diagram



Note: The large rectangle represents a piece of paper on which a concept circle diagram is drawn.

diagrams, this tool demonstrates that knowledge is constructed, that learning is the responsibility of the learner while the role of the teacher is to share meaning with the learner, and that knowledge about how one learns can enhance meaningful learning.

Concept Circle Construction

The following rules were developed over a span of three years following the writing of a paper entitled "A New Tool for the Ausubelian Toolkit" at Cornell University during the summer of 1984. The rules were revised after each semester of testing by college science students.

1. Let a circle represent any science concept.
2. Print the name of that concept (e.g., plant, temperature) inside the circle using lowercase letters.
3. When you want to show that one concept is included within another concept (e.g., all birds are vertebrates, all eukaryotic cells have a nucleus), draw a smaller circle within a larger circle. Label the smaller circle by printing the name of the narrower, more specific concept within it; label the larger circle by printing the name of the broader, more general concept within it.
4. When you want to show that some instances of one concept are part of another concept (e.g., some water contains minerals), draw partially overlapping circles. If you want to show that one of the concepts is more inclusive (broader) than the other, use a larger circle for that one. Label each circle.
5. When you want to show that two concepts are not related (e.g., no prokaryote is a eukaryote), draw separate circles and label each one.
6. You may use up to five concept circles in your diagram. They can be separate, overlapping, included, or superimposed. Label each one.

7. The relative sizes of the circles in your diagram can show the level of specificity for each concept. Bigger circles can be used for more general concepts.
8. The areas of the circles in a concept circle diagram can be used to represent relative amounts or numbers of instances of that concept. A template with openings to draw circles that appear to be 2,3,4, or 5 times larger than a standard circle is provided to make this option more attractive. If you wish to show quantities with your circles, place a small letter "n" near each concept label and enclose it with parentheses (n).
9. Time relationships can be represented by drawing nested (or concentric) circles with the oldest concept being the center one. If chronology is being shown, a "t" should be placed within the diagram near the central concept's label and it should be enclosed by parentheses (t).
10. Colored pens, markers, pencils, or highlighters may be used to color your concept circle diagram in order to make the relationships between concepts easier to visualize, understand, and recall.
11. One concept circle diagram may be connected to another by "telescoping" graphics. Telescoped diagrams should be made to read from left to right. Several stages of telescoping may be used if a large, scroll-like piece of paper is available.
12. All concept labels should be written horizontally. An exception can be made only for the largest circle, where a lengthy label may replace the upper curve of the circle.
13. Most drawings can be improved by re-drawing for greatest clarity and to leave sufficient space around the labels to give the diagram an uncluttered look.

14. Empty space (white space) around included concepts is used to imply that there are other concepts that are not mentioned. A shaded or colored area surrounding included concepts shows that no concepts have been omitted.
15. When the concept circle diagram is finished, a title that describes what the diagram is about should be written in the upper lefthand sector of the page and a sentence that summarizes what the diagram shows should be written in the area directly beneath the diagram.

Figures 4. & 5. provide examples of concept circle situations described in the rules listed above. Figure 6. demonstrates what a typical concept circle diagram looks like.

Assessment of Student-Constructed Circle Diagrams

Although an instrument to quantitatively analyze students' concept circle diagrams is currently under development, a diagram can be assessed qualitatively using the checklist items included here.

- | | | | |
|---|-----|----|------------|
| 1. Does the title fit the diagram? | Yes | No | Needs Work |
| 2. Are the concepts displayed in the proper way to show exclusive-inclusive relationships or hierarchy? | Yes | No | Needs Work |
| 3. Were time or number circles used when appropriate? | Yes | No | Needs Work |
| 4. Does the explanatory sentence fit the diagram? | Yes | No | Needs Work |
| 5. Has the student used color to clarify the meaning of the diagram. | Yes | No | Needs Work |
| 6. Are the concepts the student elected to display important to the learning goals? | Yes | No | Needs Work |
| 7. Are there any misconceptions shown by the diagram? | Yes | No | Needs Work |
| 8. Has the student followed circle construction rules? | Yes | No | Needs Work |

Figure 4. Concept Circle Conventions

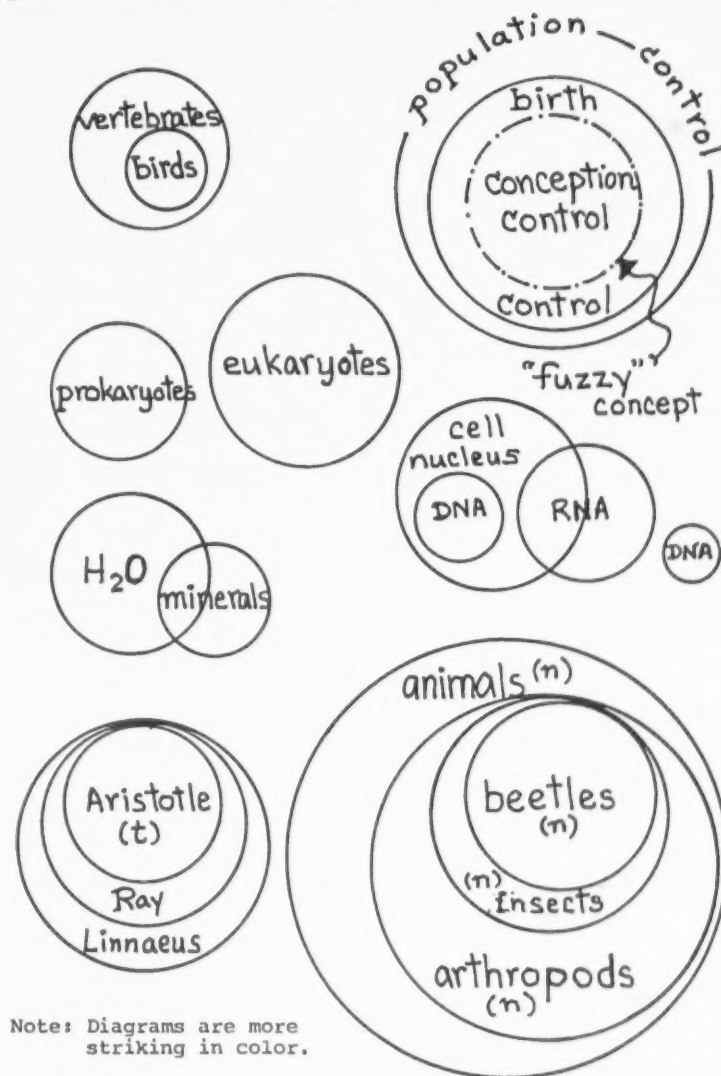


Figure 5. The "Telescoping" Convention for Connecting Concept Circle Diagrams

Note: Telescoped diagrams are to be read by revealing one section at a time--keeping the others covered by a hand or piece of blank paper. Reading is done by moving from the left diagram to the right diagram. The explanatory sentence that accompanies each section should be read right after viewing it.

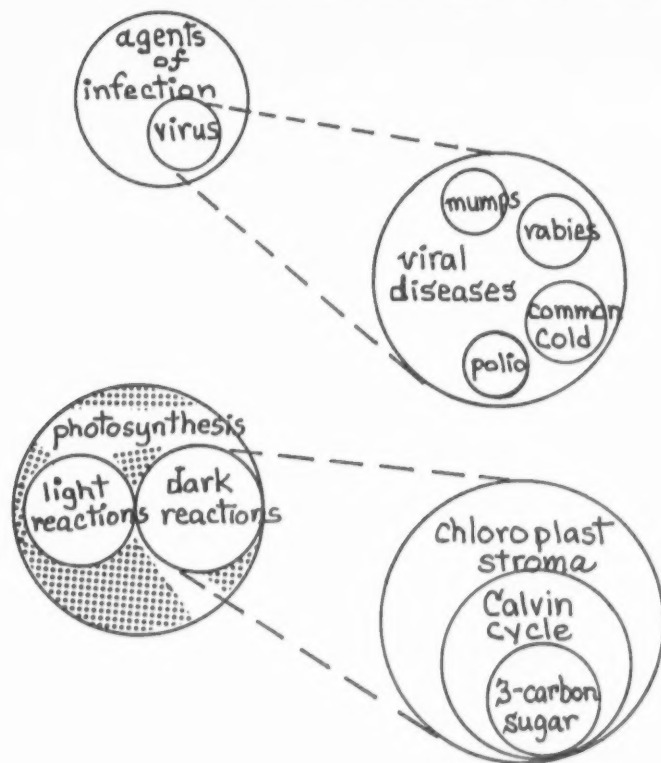
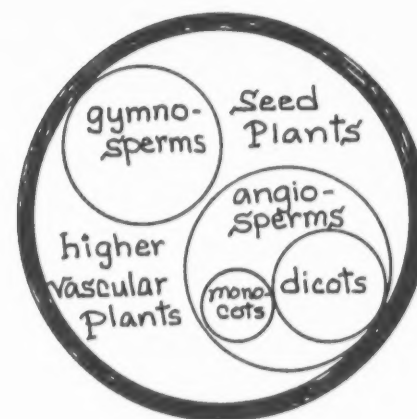


Figure 6. A Typical Concept Circle Diagram with Accompanying Title and Explanation

The Classification of Seed Plants



Seed plants (a.k.a. higher vascular plants) are divided into two taxa - gymnosperms and angiosperms. The angiosperms are subdivided into monocots and dicots.

Note: Colored shading on the original student diagram made the individual concepts more distinct.

Some Uses of Concept Circles

Metalearning Applications

In addition to the points made earlier, the following metalearning ideas can be demonstrated using concept circles:

- 1) the difference between rote and meaningful learning can be shown by using separate and related concept circles;
- 2) progressive differentiation of concepts can be illustrated by gradually adding specific concepts to an existing general concept circle;
- 3) obliterative subsumption can be shown by partially and later completely erasing the boundaries of subsumed concepts to show that those concepts can no longer be retrieved from long-term memory;
- 4) the subordinate to superordinate concept continuum can be illustrated by varying the circle sizes of concept circles;
- 5) concept formation can be distinguished from concept assimilation by first drawing many separate concept circles and then using a number of them as subsumers of newly introduced concepts;
- 6) the nature of superordinate concepts can be demonstrated by circumscribing a larger concept circle around an array of smaller ones;
- 7) conceptual hierarchy can be expressed by the telescoping technique of connecting several concept circle diagrams; and,
- 8) integrative reconciliation can be demonstrated by diagramming the differences between two apparently similar concepts (e.g., a civil law and a scientific law) or the similarities between two apparently different concepts (e.g., vegetable and botanical fruit).

Evaluation Applications

Concept circle diagrams may be useful for the following evaluation activities:

- 1) testing what a student knows about a particular subject;
- 2) identifying conceptual difficulties, misconceptions, or alternative explanations that a student harbors;
- 3) conducting clinical interviews to diagnose learning problems or answer research questions;
- 4) assessing a student's ability to extract meaning from a textbook;
- 5) structuring an examination question and then constructing an "ideal" concept circle diagram for it. (This might be used to discover the degree of correspondence between students' and teacher's diagrams, which is an indication of shared meaning,);
- 6) testing a student's ability to identify key concepts and relationships in a laboratory activity and transform them for visual display; and,
- 7) analyzing a student's ability to categorize concepts or examples in an accepted way.

Curricular and Instructional Applications

Concept circle diagrams may be useful for the following activities relevant to curriculum and instruction:

- 1) planning a classroom lesson;
- 2) analyzing a curriculum component;
- 3) demonstrating conceptual relationships during a classroom lesson at the chalkboard or overhead projector;
- 4) teaching taxonomic relationships in science classes;
- 5) satisfying the need for a variety of theoretically-sound learning activities to promote meaningful learning;
- 6) documenting the results of instruction; and,
- 7) promoting the fluent integration of thinking, feeling, and acting.

Student Attitudes toward Concept Circle Diagrams

At the close of a semester, botany students who had drawn scores of concept circle diagrams were given the opportunity to express their reactions to the technique by responding to three questions on an opinion questionnaire. The range of answers for each item is represented by a series of verbatim student comments:

- 1) What did you like most about studying science using concept circle diagrams?

Jerry--"It made me read the chapters and I became more familiar with concepts."

Lorna--"Once the diagram was made, it was very easy to study."

Shelly--"It was easy and simple--less time consuming to review."

Rick--"It encouraged thinking with reading and aided in understanding."

Heidi--"It helped me in studying for tests."

Jim--"I liked the way it illustrated ideas and thoughts."

Mark--"It compacted major ideas into a few simple circles."

James--"It helped me organize my thoughts on some confusing textbook chapters."

Michelle--"It helped me to organize the factors of a topic in my own mind. I'll use it in my own classroom."

Joel--"It made concepts very clear to me."

unsigned--"I liked it when we put them on the board and I could see other people's ideas and how they went about organizing them."

Karen--"I liked seeing how things are related and coloring the circles for emphasis."

Shelle--"They helped me remember certain difficult concepts better."

- 2) What did you like least about concept circle diagrams?

Mark--"Being imaginative."

Michelle--"Sometimes it was hard to come up with one."

Joel--"It took a long time to do just one if you were serious about getting a good one."

Shelly--"It took time to look everything up, read it, understand it, and then put it down."

Heidi--"Figuring out what to put where."

Troy--"The work and extra time needed to make a good one."

Jerry--"They were restrictive in that the number of circles to use was limited--although you could always telescope them."

Lori--"I didn't always know how to group things together."

unsigned--"Sometimes they were a pain when I had tons of other homework."

unsigned--"They tended to be very basic."

Lynn--"Having to do so many."

Carmen--"Not being able to use them on tests."

unsigned--"I'm used to studying my notes and it was hard to switch to a new study aid."

- 3) For what ideas did the concept circle diagrams seem most appropriate?

Jim--"family relationships"

Mark--"major ideas"

Carmen--"concepts that fit together"

Shelly--"time sequence and parts of wholes"

Heidi--"things with details or branches of information"

James--"sequential or family relationships"

Shelle--"summarizing a chapter"

Joel--"closely related subjects"

Lorna--"factors affecting ..."

unsigned--"ideas that can also be put into outline form"

Jerry--"concepts containing a number of components or steps"

unsigned--"testing our understanding"

Rick--"time relationships"

James--"I think they help show relationships in an understandable way."

A Preliminary Assessment of Concept Circles

Often the introduction of a new instructional technique is accompanied by a plethora of unsubstantiated claims. Concept mapping and vee diagramming have been tested in a variety of educational settings and their value as meta-cognitive tools and instructional aids has been documented. It is premature to judge whether or not concept circle diagrams will join them as a valuable tool for meaningful learning. The purpose of this paper was to describe, compare, contrast, explain, then anticipate applications for concept circle diagrams.

If what has been presented in this paper withstands close scrutiny, I see that following features of concept circle diagramming as its strengths:

- 1.) it is a way of introducing students to the basic concepts of metalearning prior to concept mapping;
- 2.) it is especially appropriate for examining inclusive/exclusive relationships between bounded, taxonomic concepts;
- 3.) it is an alternate way of encouraging students to reflect on what they are learning and to share meaning through words and diagrams;
- 4.) it demonstrates that principles of graphic perception can be used in constructing a metacognitive tool; and,
- 5.) it yields an approximation of what the learner knows about a prescribed subject and can also reveal conceptual difficulties, misconceptions, and alternative explanations students harbor.

Moving Forward

Kosslyn (1980) contends that much of what we know can be represented in several different ways (e.g., propositions, images) and that particular representational formats may be most efficient for performing various cognitive tasks. In addition to subject-specific diagrammatic tools, science educators need broadly applicable diagrammatic tools to help students understand how science works to produce new knowledge and to help students learn how to learn science.

In partial response to the important issue raised by Texley (1984) in an editorial to the readers of The Science Teacher in which she wrote: "Despite our shared desire to teach relevant, meaningful science, publishers and institutes of teacher education have provided teachers with few tools to assess more than rote memory," concept circle diagrams (along with concept maps and vee diagrams) may be used not only to promote learning and understanding but to assess it as well.

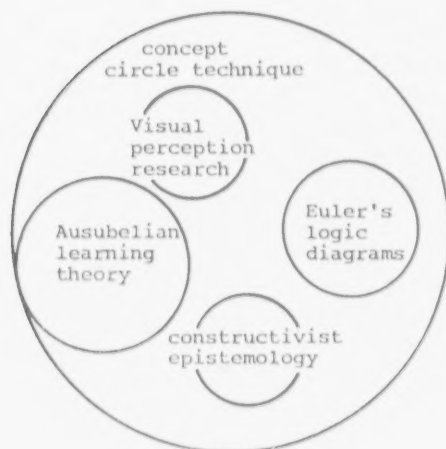
Because this is a paper about a new metacognitive tool, it seems appropriate to summarize the conceptual relationships that were stressed in this paper by using concept circle diagrams. Figures 7, 8, and 9 are included for that purpose.

Stigler (1984) concluded: "Indeed, perhaps the most powerful tools a culture can provide to the developing child will come in the form of specialized mental representations that are passed down through education." Perhaps the concept circle diagram is such a tool to be shared with today's children.

At the end of their seminal article introducing educators to the concept mapping technique they developed, Stewart, Van Kirk, and Rowell (1979) invited use and testing of the technique by others "in order to add empirical validity to the idea." I extend a similar invitation for concept circle diagrams.

Figure 7.

Components of the
Concept Circle Technique

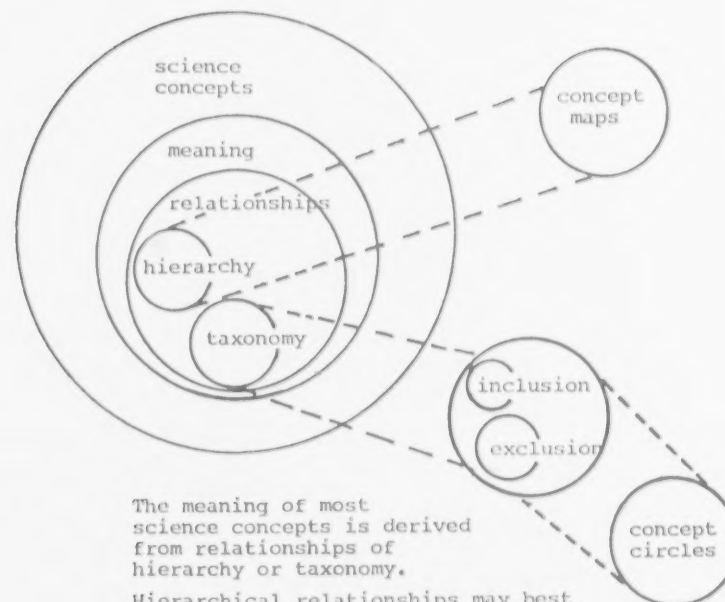


The concept circle technique has its roots in Ausubelian learning theory, Leonhard Euler's logic diagrams, visual perception research, and modern constructivist epistemology.

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Figure 8.

A Comparison of the Strengths of
Concept Maps and Concept Circle Diagrams
in Revealing Cognitive Structure of the
Learner

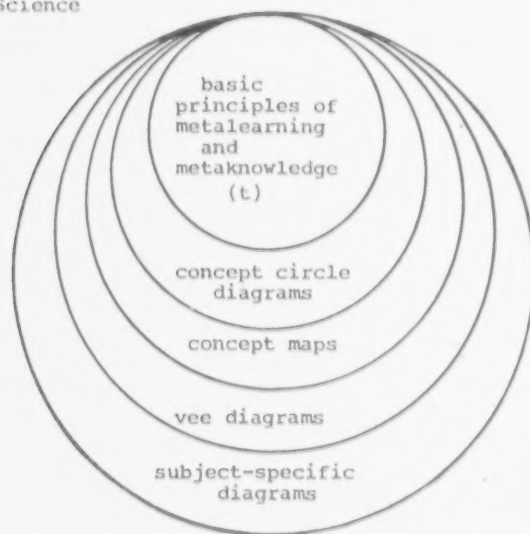


The meaning of most science concepts is derived from relationships of hierarchy or taxonomy.

Hierarchical relationships may best be revealed using concept maps; taxonomic relationships (especially inclusive-exclusive ones) may best be revealed using concept circle diagrams.

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A Proposed Sequence of Instruction
Using Diagrams to Learn How to Learn
Science



It is proposed that students be taught how to learn science using diagrams presented in this order: basic principles of metalearning and metaknowledge, concept circle diagramming, concept mapping, vee diagramming, and subject-specific diagramming.

References

- Adams, J. L. Conceptual blockbusting. New York: W. W. Norton, 1979.
- Arnaud, M. W., Mintzes, J. J., Dunn, C. S., and Shafer, T.H. Concept mapping in college science teaching. Journal of College Science Teaching, 1984, 14(2), 117-121.
- Arnold, B. H. Set theory. In Encyclopedia Americana, 1983.
- Briggs, J. The genius mind. Science Digest, 1984, 92(12), 74-77, 102-103.
- Cleveland, W. S. The elements of graphing data. Monterey, CA: Wadsworth Advanced Book Program, 1985.
- Dooley, R. P., & Harkins, L. E. Function and attention-getting effects of colour on graphic communications. Perceptual and Motor Skills, 1970, 31, 851-865.
- Duffety, M. C. Leonhard Euler. In Collier's Encyclopedia, 1980.
- Dumitriu, A. History of logic (Vol. 4). Tunbridge Wells, Kent, England: Abacus Press, 1977.
- Dunn, C. S. The influence of instructional methods on concept learning. Science Education, 1983, 67(5), 647-656.
- Dwyer, F. M. The effect of IQ level on the instructional effectiveness of black and white and colour illustrations. Audio Visual Communications Review, 1976, 24, 49-62.
- Gardner, M. Logic machines, diagrams, and Boolean algebra. New York: Dover Publications, 1968.
- Gastev, I. A. Logic diagram. In Great Soviet Encyclopedia, 1977.
- Gunstone, R. F., & White, R. T. Assessing understanding by means of Venn diagrams. Science Education, 1986, 70(2), 151-158.
- Hallstone, M. A case for standardisation in the preparation of graphs and diagrams. Medical and Biological Illustration, 1973, 23, 8-12.
- Holliday, W. Using visuals to teach concepts. Science and Children, 1980, April, 9-10.

- Howard, V. A., & Barton, J. H. Thinking on paper. New York: William Morrow, 1986.
- Judson, H. F. The search for solutions. New York: Holt, Rinehart, and Winston, 1980.
- Kaplan, E. H. Problem solving in biology (3rd ed.). New York: Macmillan, 1983.
- Kosslyn, S. M. Image and mind. Cambridge, MA: Harvard University Press, 1980.
- Kuzicheva, Z. A., & Novoselov, M. M. Logic. In Great Soviet Encyclopedia, 1977.
- Leisten, J. A. Venn diagrams in chemistry. The Science Teacher, 1970, 37(2), 76, 78.
- Levy, G. B. " . . . what is out front." American Laboratory, 1987, 19(4), 10.
- March, R. H. Physics for poets (2nd ed.). New York: McGraw-Hill, 1978.
- McDonald, W. A. Hieroglyphic. In The World Book Encyclopedia, 1958.
- Miller, G. A. The magical number seven, plus or minus two. Some limits on our capacity for processing information. Psychological Review, 1956, 63, 81-97.
- Novak, J. D. A theory of education. Ithaca, NY: Cornell University Press, 1977.
- Novak, J. D. Applying learning psychology and philosophy of science to biology teaching. The American Biology Teacher, 1981, 43(1), 12-20.
- Novak, J. D., & Gowin, D. B. Learning how to learn. New York: Cambridge University Press, 1984.
- Novak, J. D., Gowin, D. B., & Johansen, G. T. The use of concept mapping and knowledge vee mapping with junior high school students. Science Education, 1983, 67(5), 625-645.
- Parker, S. P., editor. McGraw-Hill dictionary of scientific and technical terms (3rd ed.). 1984.
- Reese, W. L. Dictionary of philosophy and religion. Atlantic Highlands, NJ: Humanities Press, 1980.
- Reynolds, L., & Simmonds, D. Presentation of data in science. The Hague, Netherlands: Martinus Nijhoff Publishers, 1981.
- Silano, A. A. Conceptogrammatic materials in the teaching of elementary science. Science Education, 1958, 42(5), 436-439.
- Smith, E. E., & Medin, D. L. Categories and concepts. Cambridge, MA: Harvard University Press, 1981.
- Stevens, S. S. Psychophysics. New York: John Wiley & Sons, 1975.
- Stewart, J., Van Kirk, J., & Rowell, R. Concept maps: A tool for use in biology teaching. The American Biology Teacher, 1979, 41(3), 171-175.
- Stigler, J. W. Mental abacus: The effect of abacus training on Chinese children's mental calculation. Cognitive Psychology, 1984, 16(2), 145-176.
- Stuart, H. A. Should concept maps be scored numerically? European Journal of Science Education, 1985, 7(1), 73-81.
- Texley, J. Editor's corner. The Science Teacher, 1984, 51(3), 9.
- Toth, M. A. Figures of thought: The use of diagrams in teaching sociology. Teaching Sociology, 1980, 7(4), 409-424.
- Van Amerongen, C. The way things work book of the body. New York: Simon and Schuster, 1979.
- Venn, J. Symbolic logic. New York: Chelsea Publishing Company, 1894 (reprinted 1971).
- Winn, W. Effect of attribute highlighting and diagrammatic organization on identification and classification. Journal of Research in Science Teaching, 1981, 18(1), 23-32.

Schooling and the development of metacognition

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Introduction

The basic purpose of the study is to develop an instrument to measure metacognition and to determine the effects of schooling on metacognition.

The concept metacognition is introduced by Flavell (1976). He defined metacognition as "knowledge that takes as its object or regulates any aspect of any cognitive endeavor" (In: Brown & Campione 1981, p.521). Since then the term has been used in the developmental area to refer to somewhat separate phenomena: knowledge about cognition and regulation of cognition. The first phenomenon is concerned with a person's knowledge about his own available cognitive means. The second is primarily concerned with self-regulatory mechanisms during an ongoing attempt to learn or solve problems.

It is the second class of activities we are concerned with in this paper. This class of metacognitive activities involves content-free strategies or procedural knowledge such as self-interrogation skills, self-checking, and so forth. In other words it is an activity by means of which the learner manages his (or her) own thinking behavior. Brown (in Meichenbaum c.s 1985) summarizes these metacognitive activities as including:

1. Analyzing and characterizing the problem at hand;
2. Reflecting upon what one knows or does not know that may be necessary for a solution;
3. Devising a plan for attacking the problem;
4. Checking or monitoring progress.

A central problem in the research area on metacognition is the adequacy of the assessment techniques designed to measure metacognition. Meichenbaum, Burland, Gruson & Cameron (1985) consider

several different techniques that can and have been employed to study metacognitive activities in children. The assessment procedures considered are interviews administered both concurrently and on a post performance basis, concurrent think-aloud assessments and task and performance analyses. They point out both the advantages and disadvantages of these techniques. One of the pitfalls of the interview and think-aloud techniques is that the data yielded by such techniques are problematic. The most serious problem has to do with the interpretive difficulties that arise from a subject's inability to verbalize answers or thinking pattern. The absence of an adequate response does not necessarily mean that the subjects were not involved in metacognitive activities. Gruson, for example, showed that there are subjects who, on the basis of observations, manifest consistent strategies, but who fail to verbalize such strategies. The same pattern was also observed in Burland's and Cameron's data. Thus, the use of interview and think-aloud techniques raises an important theoretical issue: do we indeed limit the definition of metacognition to the subject's abilities to verbalize strategies?

A somewhat different approach without the above mentioned pitfalls is to assess metacognitive involvement on the basis of performance directly without the subject's self-report, either concurrently or during post performance. Gruson (1985) has shown that it is possible to infer the use of metacognitive strategies on the basis of repeated patterns evident while carrying out the task. Examples of how one can formally conduct metacognitive assessment without using self-report comes from the work of Sternberg (1983), Butterfield, Wambold & Belmont (1973) and the Soviet-psychological work of Isaev (1984) and Zak (1985).

In our research on metacognition we developed the line of investigation introduced by the Soviets, i.e. conducting metacognitive assessment directly on performance, making less use of verbal questioning and focusing more on behavioral observations. The results of studies done by Isaev (1986) revealed three basic strategies which in turn are used to measure metacognitive functioning; namely manipulative, empirical and theoretical. A manipulative strategy consists of actions or moves that are not guided by the goal. A move is made correctly, but is made because moving has to be done. A move does not derive from the subject's preceding move and is not the basis for the next move; the moves are not linked together. Mostly a large number of superfluous moves is needed to reach the end result. Subjects using an empirical strategy approach the task through moves or actions that, step by step, change the situation. The subject expects a specific result from a move and takes that into account when making the next move. Subjects using a theoretical strategy think over their solution process beforehand. These subjects continue the search in their mind until they find the most efficient way of solving the task, sometimes testing up to three or four nonoptimal alternatives. These subjects find the most efficient way of solving the task during the first or second item.

Brown's (1978) four categories: analyzing, reflecting, planning and checking are in keeping with the Soviets description of the theoretical strategy. In both cases the inference is made that a subject thinking about a task is able to do so in a deductive

manner. However the Soviet psychologists see the issue of reflective thinking or metacognition as a continuum beginning with manipulative strategies and eventually progressing towards the more theoretical strategies. The tasks measuring metacognition in this study are designed in a manner that allows the observer to draw inferences about the level of metacognitive functioning. The task itself is constructed to elicit differential strategies when the tasks are solved. Associated with the task are specific scoring procedures, that reflect the different strategies used by subjects when solving a given task. For example, the tasks of this study scored 1-3 reflect responses that are categorized as manipulative, likewise the remaining responses categorize either empirical or theoretical responses. The tasks and scoring are also designed so that subjects who change strategies may also be identified. In addition the tasks are novel to the subject and require no special knowledge. Moreover, subjects are motivated to do the task which are constructed so that nobody can do it wrong, there must be no failure. The only thing that matters is the way in which the subject handles the task.

METHOD

Subjects

Four populations were used for this study. Two populations were selected from "regular" Dutch schools and two populations from "special" schools with mentally retarded children or slow learners. The regular and special schools each were represented by schools with predominantly ethnic minorities and schools with predominantly Dutch students. Students from the regular schools varied in age from 6-13 and students from the special schools varied in age from 8-13, because hardly any 6- and 7 year olds go to the special schools. Fig.1 illustrates the populations for the study.

	ethnic minority	native dutch	total
regular	24	110	134
special	26	29	55

fig.1 Populations and number of subjects

Procedure

Three metacognitive tasks: the strip-, tower- and mole task were administered individually to all subjects in two 30- minutes sessions. In the first session the strip- and tower task was given to the subjects and in the second session the mole task. The tasks were administered by an experimenter giving the instructions and an observer making the protocols.

Instruments

Three tasks were used: the strip task, the tower task and the mole task. Instruction and scoring of these tasks will be illustrated by a detailed description of one of the tasks: the strip task.

STRIP TASK

The strip task was originally developed by the Soviet psychologist Zak (in Wolters 1982) and was designed to measure reflection as the dominant metacognitive skill.

The material used is a plate with an area of 30 x 60 cm on which two parallel lines, with a distance of 15 cm. Strips are used in the following numbers and measures:

stripindex	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
length	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
number	10	10	10	5	5	5	3	2	1	1	1	1	1	1	1	1

The length is given in cm. All strips are 3 cm wide

SET UP

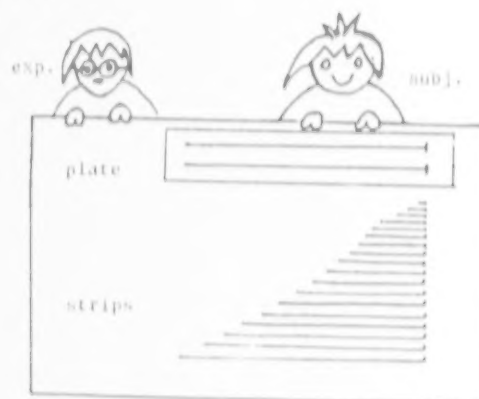


fig.2 Set up of strip-task

INSTRUCTION

The instruction to the subjects is as follows. The subject is shown a model strip and asked to make a strip the same length as the model. The subject is given a number of strips of varying length and then told a specific number of strips to use when constructing a length equal to the model (fig.1). It is emphasized that he has to think carefully before setting out to solve

the task.

Before starting the items two introductory items are presented: first a model strip with a length of 9 units is presented and the subject is instructed to build a matching strip with two parts. The item is coded as 9(2); the 9 indicating the length of the model and the (2) indicating the number of parts to be used in matching the model.

Task items: 10(4), 14(5), 13(6), 12(7)

After the subjects have done four items they are given instructions designed to encourage them to think about the task before they actually begin to select the strips to match the model. They are told "from now on we will see how much time you need to do a strip". The subjects are told that they can take as much time as they want to think about the problem and that they will be timed only when they begin selecting and placing the strips. For this second phase four additional items are presented to each student. This second phase is used to determine if students change the strategy they used in the first phase as a result of the introduction of instruction prior to the second phase items. Performance time is taken for items: 16(9), 15(8), 11(7) and 13(6). One item 13(6) is used twice, once before time instruction and once after time instruction. This item is meant as an extra check to see if subjects change their strategy.

SCORING

ITEM SCORING

score 0

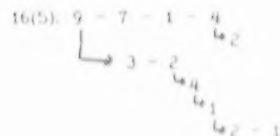
Subject does not understand the instruction despite repeated explanation.

Manipulative category (includes scores 1,2 and 3)

This category includes behaviors that are haphazard and without any planning. The subject is unaware of the end result until after it has been accomplished. It is only at that time that the subject recognizes that the task is completed. The subject behaves according to the rules attempting to match the model in length but loses track of the requested number of strips. The subject placed in this category is characterized by placing and replacing the strips ("removing behavior") eventually using the correct number of strips with less and less removing behavior.

score 1

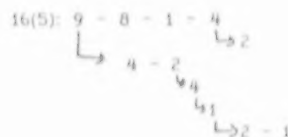
The subject shows "removing behavior". That is, a subject puts down one or more strips, removes all or some of them, and starts all over again. Sometimes the item eventually goes wrong because of all the removing the subject has forgotten the number of strips to use. Mostly the subject is satisfied as soon as she or he has the proper length.



score 1 example: size 9 strip is removed and replaced by size 3 and size 2, 2 is removed and replaced by 4 etc. In the end the length is correct, but there are six strips instead of the required five.

score 2

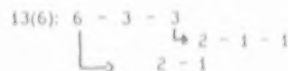
The subject shows removing behavior, but eventually each item is correctly carried out.



score 2 example

score 3

One or two strips are removed and replaced.



score 3 example

Empirical category (includes scores 4 and 5)

This category implies that a subject has a strategy in mind, characterized as inductive and recognizes the goal of the task. The subject has no need to remove strips once they are placed, but rather adjusts the size of the strips as the task is being solved. The behavior of the subject is in a step by step fashion, placing one or two strips, making a decision, placing another strip and adjusting the next and continuing in this fashion until all the strips are correctly placed. The distinction between score 4 and score 5 is the size of the "step", with the number of strips considered together larger in those scored 5 than 4.

score 4

The subject shows non-removing behavior. The strips are put down one by one. In the following illustration the subject places a size 2 strip and counts aloud one and continues to count aloud as each strip is placed, finally placing the last strip and saying "7".

12(7): 2 - 1 - 2 - 3 - 1 - 3 - 1

score 4 example

score 5

The subject puts down the strips one by one. There are strips with only two different lengths and these two different strips are joined together. In the following illustration the subject places five 2-strips one by one and then says this is "five" and I need two more.

12(7): 2 - 2 - 2 - 2 - 2 - 1 - 1

score 5 example

Theoretical category (includes score 6 and 7)

The behavior in this category is the most efficient as the subject proceeds in a deductive manner. The subject does all the planning prior to the time he actually does the placement of the strips. In this fashion the subject takes a stack of strips one less than the necessary number, places these in correspondence to the model and then determines the size of the last strip completing the comparison.

score 6

The subject picks up a pile of small strips one less than the required number, put them quickly down and adds the last strip to make it equal. An estimation error is sometimes made with the completing strip.

15(8): 1 - 1 - 1 - 1 - 1 - 1 - 1 - 7₄₈

score 6 example

score 7

The same behavior as with score 6 is shown, but without estimation errors.

15(8): 1 - 1 - 1 - 1 - 1 - 1 - 1 - 8

score 7 example.

SCORING OF METACOGNITIVE LEVELS

The strip, tower and mole task each consist of 8 items. After four items a moment of reflection for the subject is induced. This happens indirectly by way of a special instruction. In the strip task a reflection moment is induced, as we have seen, by indicating to the subject the need to think before solving the task which is timed.

The activity in the tower task is to find a specific tower by asking questions about the properties of the different towers.

The goal is to find the tower in a minimal number of questions. The activity in the mole task is to find the shortest route of a mole to his foodplace in a structured garden. In each task after four items the subject is given the opportunity to think about the efficiency of the strategy used and possibly change the strategy to a more efficient one.

For each of the three tasks a score-level was calculated by taking the mean score over the eight items.

Apart from a score-level a so called code-level was calculated, indicating the effect of the moment of reflection induced halfway each task. The procedure to obtain the code-level for each task is as follows: for each of the three tasks for the first four items and the second four items scores were placed in one of the three categories: manipulative - empirical - theoretical. It was then possible to obtain a coded score for each subject on each of the three tasks based on whether or not the strategy changed from the first to the second phase of each task. These coded scores were placed in a numerical hierarchy from 1 to 7 with a code-level of 1 demonstrating the strategies using the least metacognition and a code-level of 7 demonstrating the most. For example, a subject with a code-level of 1 on the strip task would have used a manipulative strategy for the first four items and continued with a manipulative strategy for the four items after reflecting was requested. A subject coded 6 uses an empirical strategy for the first four items and changes to a theoretical strategy for the second four items. Fig.3 illustrates the seven code-levels that were used. A student with a mean score smaller than 3.50, falling between 3.50-5.00, or greater than 5.00 was classified as manipulative, empirical or theoretical respectively. The criteria for change from the first four items to the second four items is that the difference between the mean score achieved on the second four items had to be equal or greater than 0.75 than the mean score achieved on the first four items. In addition the mean score for the second four items had to fall in a category above the mean score of the first four items.

	mean score item 1-4	mean score item 4-8
code 1	manipulative remains	manipulative
code 2	empirical changes	manipulative
code 2	theoretical changes	manipulative
code 3	manipulative changes	empirical
code 4	empirical remains	empirical
code 5	theoretical changes	empirical
code 6	empirical changes	theoretical
code 7	theoretical remains	theoretical

fig.3 Calculation of the code-levels

Results

VALIDATION

To validate the measure of metacognitive skill, we computed correlations between the three tasks on score- as well as code-level. All the correlations fall between .49 and .69 and are significant ($p < .005$). Therefore, the metacognitive measures are related highly to each other.

ETHNIC MINORITY AND NATIVE DUTCH POPULATIONS

The means and standard deviations of the score-level over the three tasks for the respective populations are: ethnic minority 3.79 (SD = 1.16); native dutch 4.17 (SD = 1.23). For differences among means, a t-test revealed a non-significant difference between ethnic minority and native dutch populations ($t = 1.87$, $p = .06$). The means and standard deviations of the code-level for the respective populations are 3.70 (SD = 1.62) and 3.91 (SD = 2.08). A t-test revealed an even smaller non-significant difference between ethnic minority and native dutch populations ($t = 0.74$, $p = .46$). When we look at the two populations within the regular and special schools respectively, results similar to the above are obtained.

Thus, with respect to metacognitive measures we are dealing with one population instead of two. This is different from what we would expect, for, when scoring scholastic achievements ethnic minorities score lower than native students. One explanation for this finding might be that the tasks at hand are less culture bound than the scholastic tasks. Another explanation could be that these tasks do not in any way measure verbal skills. For any further data analysis we will not make a distinction between ethnic minority subjects and native dutch subjects.

REGULAR AND SPECIAL SCHOOLS

All subjects are assigned to grades according to their chronological age. One has to bear in mind that a student from the special school with the same chronological age as a student from the regular school does not have a mental age comparable to the regular student. For reasons of simplicity we have only made groups on the basis of grades according to chronological age. For example a 10-year old special school student is classified as a fourth grader. This also means that for the special schools we have no groups of first and second graders, because there are hardly any 6 and 7 year olds in special schools.

The results of a trend analysis of score-level over the three tasks with grade for the two schooltypes is depicted in fig. 4. The correlation between score-level and grade is for the special school group .19 ($p = .08$) and for the regular school group .47 ($p = .005$), indicating that the increase of score-level with grade is significant for the regular school subjects and that there is no significant increase with grade for the special

school subjects. Similar results are obtained for each task separately.

Means, standard deviations, t-values and p-values of metacognitive score-level over the three tasks for grades 3-5 for the respective schooltypes are given in table 1. A significant difference on metacognitive score-level between the regular - and special school students is not found until the students are in the fourth grade, when they are about 10 years of age. The impression is that before age 10 the differences on metacognitive score-level are not yet manifested. Before interpreting and discussing the preceding results, we will consider the results on metacognitive code-level first.

The results of a trend analysis for metacognitive code-level over the three tasks with grade for the two schooltypes is depicted in fig. 5. The correlation between metacognitive code-level and grade is for the special school group .09 ($p = .23$) and for the regular school group .46 ($p = .001$). Metacognitive code-level shows even more clearly than metacognitive score-level that the regular school subjects develop significantly with age with regard to metacognitive skill. Apparently, the special school subjects do not show a significant rise in metacognitive code-level from age 8 through 13. Similar results are obtained for each task separately.

Means, standard deviations, t-values and p-values for metacognitive code-level over the three tasks for grades 3-5 for the respective schooltypes are shown in table 2. For metacognitive code-level, as is shown in table 2, the significant difference between special school subjects and regular school subjects does not appear at grade 4, as was the case with the metacognitive score-level, but one year later at grade 5.

Discussion

METACOGNITIVE SCORE-LEVEL AND METACOGNITIVE CODE-LEVEL

Is it relevant to make a distinction between metacognitive score-level and metacognitive code-level? The results of this study show clearly that metacognitive score-level and metacognitive code-level are related but distinct measures. The respective graphs in fig. 4 and 5 indicate a difference in slope and starting point. The slope of the metacognitive code curve is steeper than the curve for the metacognitive score curve for both the regular and special school group. The regular school subjects seem to start at a lower level in the first grade for the metacognitive code-level compared to the metacognitive score-level. The difference in starting-point for the special school subjects, when they have the age of a third grader, is difficult to judge because there is not much change anyhow in both the score and code curve over the grades.

grade	regular		special		t-value	p-value
	mean	SD	mean	SD		
3	4.27	1.18	3.31	1.88	1.62	.13
4	4.85	.76	3.41	1.70	2.45	.03*
5	4.64	.57	3.73	1.08	2.88	.009**
6	4.92	.81	4.00	.56	3.76	.001**

table 1 Results of a t-test for differences among means of score-levels for grades 3-6. *Significantly different with $p < .05$; **significantly different with $p < .01$

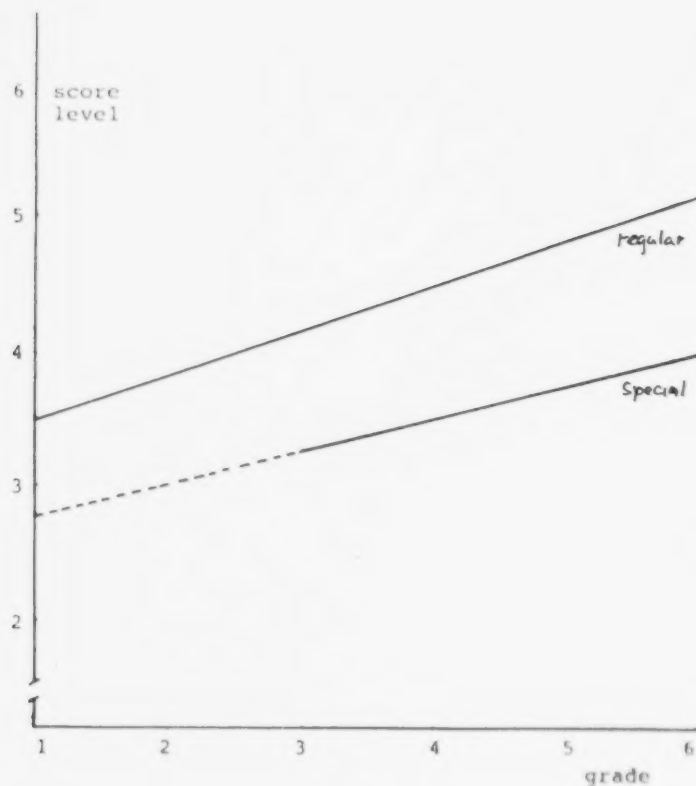


fig.4 The relation between metacognitive score-level over the three tasks and grade for special and regular schooltypes.

grade	regular		special		t-value	p-value
	mean	SD	mean	SD		
3	4.04	1.69	2.66	2.50	1.73	.10
4	4.45	1.76	3.64	2.43	1.21	.23
5	4.82	1.39	3.47	1.55	2.79	.01*
6	5.25	1.34	3.36	1.51	4.12	.00**

table 2 Results of a t-test for differences among means of code-levels for grades 3-6. *Significantly different with $p < .05$; **significantly different with $p < .01$.

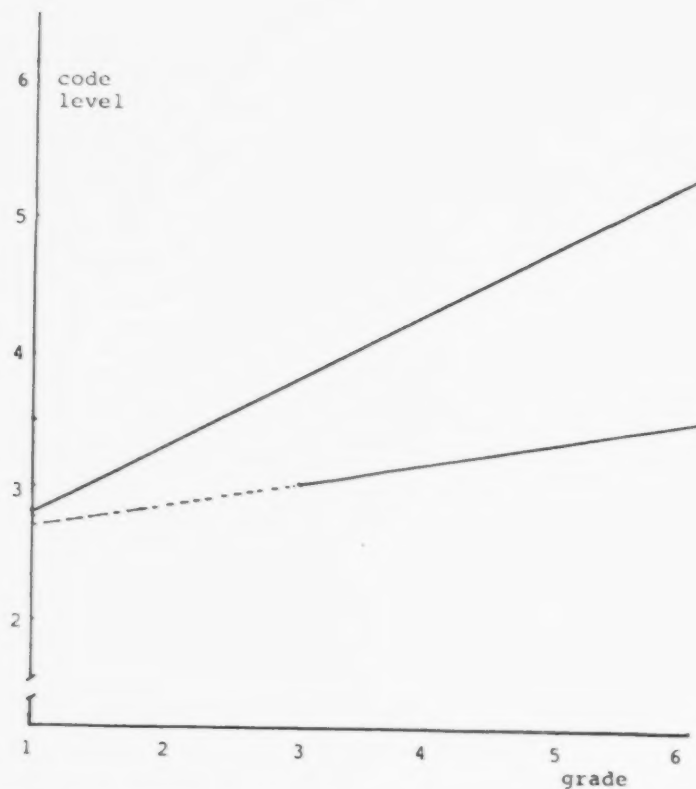


fig.5 The relation between metacognitive code-level over the three tasks and grade for special and regular schooltypes.

The difference in definition between score-level and code-level has to do with measuring and identifying a change in strategy, after reflection has been asked for. A change in strategy is explicitly represented in the code-level and this is not so in the score-level. So the metacognitive code-level gives information about the kind of strategy a subject uses and a possible change in strategy whereas the metacognitive score-level does not give this information. For example, a subject using a theoretical strategy for the first four items and then switching to an empirical strategy for the second four items might score the same as a subject switching from empirical to theoretical. The first subject, however, would be assigned to code-level 5 and the second subject to code-level 6. This is one of the reasons why we prefer the metacognitive code-level as a measure for metacognitive skill. But there is another reason why we prefer the metacognitive code-level above the metacognitive score-level. When extrapolating the code-level curve of the special school group to the first grade there is no difference in starting point for the two groups. The special school student and the regular school student both start in the first grade at the same metacognitive level. Fig 5 corresponds more with reality than fig.4. Usually at the start of the first grade there are no noticeable differences yet between retarded and nonretarded students. Only in the course of the first or second grade a difference is noticed by the teacher and then the students may be referred to a special school. The results of various other studies mention this phenomenon (Brown 1978). It is in the context of schools, particularly in the later grades, that great emphasis is placed on decontextualized skills of knowing, the learning to learn skills. The slow learners or the mentally retarded are the ones who have problems grasping these skills and consequently they are diagnosed as slow learners.

METACOGNITIVE DEVELOPMENT, RETARDED AND NONRETARDED STUDENTS

It is obvious from fig.5 and table 2 that special school students and regular school students differ in metacognitive skills and development. Metacognitive development of the special school students is impaired. There is a significant rise in metacognitive level for the regular school student but not for the special school student. With the results of this study it might be possible to identify characteristics of metacognitive functioning which are lacking or reduced in retarded students relative to nonretarded students and which are wholly or in part responsible for the observed performance differences on the tasks presented.

At this point we would like to recall some characteristics of the metacognitive code-levels. There are as we have seen, three levels where a strategy remains the same for the first and second phase of the task: level 1, 4 and 7. Level 1 indicates a manipulative or haphazard strategy throughout the task. Level 4 indicates an empirical or inductive strategy throughout the task. Level 7 indicates a theoretical or deductive strategy throughout the task. Level 3 and 6 are interesting metacognitive levels from

a developmental point of view. In these two levels a progressive change is taking place. In level 3 the student uses a manipulative strategy in the first phase of the task, and after requested reflection changes the strategy to an empirical one which is higher in the metacognitive hierarchy. In level 6 a change takes place from an empirical strategy to a theoretical strategy. A student using a theoretical strategy, i.e. using the most metacognition, is able to select, modify and sequence actions into an overall plan or procedure and then oversee and evaluate the efficacy of the approach selected. By introducing a moment of reflection halfway the task, as we did in our research, we urge the student to do just that, use his or her metacognitive potential and evaluate the effectiveness of the strategy used during the first phase of the task.

The special school group is a homogeneous one in that no one is classified as attaining code-level 7, whereas some of the regular students in the higher grades do indeed reach level 7. Characteristic for a 10-year old average regular student is the use of an empirical strategy, whereas an average 10-year old retarded student is characterized by the use of a manipulative strategy or a strong inconsistency in strategy use, i.e. lacking any plan to form a plan resulting in haphazard behavior. This characteristic is one aspect in which a retarded child differs from a nonretarded child of comparable chronological age.

Although according to table 2 the differences in metacognitive code-level between retarded and nonretarded children become significant only in grade 5, care must be taken not to draw premature conclusions. Such a conclusion could be that this metacognitive difference only arises at this time, because in the lower grades it is not significantly manifest. It is most likely however, that this slowed down metacognitive development has been going on for quite a while. Why it is necessary to pay attention to this point is explained in the next paragraph.

We write about the group of retarded children as though it were a homogeneous one while in fact it is a heterogeneous group of children. It is true that retarded children often did use a manipulative strategy, but there were also retarded children who changed their manipulative strategy into an inductive strategy (level 3) after reflection was requested and some children even used an inductive strategy throughout the task. Our main concern at this point is the level 3 children, the children who profit from reflection. Contrary to the common opinion that retarded children lack any metacognitive skill and that it is useless to call on it, these children can progress in their metacognitive development and with whom instruction aiming at reflective thinking may be effective. Rather the question is whether at the special school these very children receive the instruction that gets them started to make use of their metacognitive potential. Because, if these children are not stimulated by explicit instruction then their metacognitive development will not progress. As shown above prompting is a necessary condition for these children.

The results of this research show that not only there are definitely differences in metacognitive development between retarded and nonretarded students but also that some retarded students tend to use their metacognitive potential if they are motivated to do so.

References

- Brown A.(1978) Knowing when, where, and how to remember: A problem of metacognition. In R.Glaser (ed.), *Advances in instructional psychology*. Hillsdale, NJ: Erlbaum.
- Brown A. & J.C. Campione (1981) Inducing flexible thinking: The problem of access. In M.P. Friedman, J.P. Das & N. O'Connor, *Intelligence and learning*. New York.
- Butterfield E., Wambold C., & Belmont J. (1973). On the theory and practice of improving short-term memory. *American Journal of Mental Deficiency*, 77, 654-669.
- Flavell J. (1976) Metacognitive aspects of problem solving. In L. Resnick (ed.), *The nature of intelligence*. Hillsdale, NJ: Erlbaum.
- Isaev E.I. (1985) Psychological description of young childrens planning methods. *Soviet Psychology* 1,35-50.
- Meichenbaum D., Burland S., Gruson L., & Cameron R. (1985). Metacognitive assessment. In S.R. Yussen (ed.), *The growth of reflection in children*. A.P., London.
- Sternberg R.J.(1983) Components of human intelligence. *Cognition*, 15, 1-48.
- Wolters M.A. (1982) Cognitieve ontwikkeling meetbaar? *Psychologie en Maatschappij* 1,75-82.
- Zak A.Z.(1983) The development of mental acts in first to tenth graders. *Voprosy Psichologii* 1,43-50 (in russ.).

Cognitive and Affective Outcomes for Junior High Students Using Two Electricity Simulations Produced by the Microcomputer Software in Science Project

by

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Introduction

The Microcomputer Software in Science Project began in Sept., 1984 after competition for award of a development contract from a major, non-profit, New York State electric utility company. The contract called for classroom teacher participation in the development and testing of electricity concepts which were to be programmed for use in sixth through ninth grade science classes. There was to be free distribution of the resulting software and ancillary materials to all interested middle school/junior high school teachers in New York State.

Approximately 50 teachers participated in explicating the concepts and pedagogy to be used with average students at the targeted grade levels. Simulation programs were chosen by the teachers as the type of software best suited to use in typical science classrooms across New York State. Because of their popularity in New York State the Apple II+ and Ile systems were chosen as the machines for which programs would be written.

The entire development process for the programs resulting from the project is described in a paper being prepared for publication by the author. Detailed reports on the first and second rounds of project software testing are contained in doctoral dissertations prepared or being prepared by students of the writer.

This report is intended to make available a preliminary quantitative assessment of the cognitive and affective outcomes resulting from use of software produced during the three-year development project at Teachers College, Columbia University. Quantitative evaluations of any type of software are rarely attempted and even more rarely reported in the literature available to teachers and teacher educators. Therefore, it is difficult to make informed decisions on the types of software or software titles that would be most efficacious in a particular science program. It

is hoped that this paper will be seen as one effort to begin a dialog through which science teachers and science education faculty in colleges can take a more active role in specifying criteria for development and use of computer software in school settings.

Software content concepts and goals

Seven, menu driven simulation programs were conceptualized by project teachers and staff. Of these, two were chosen for programming by another contractor working for the electric utility company.

The first simulation, Watts in a Home, focuses on concepts relating to the logical and efficient use of home appliances during part of a typical day. Teams of two students attempt to function within a budget for electricity cost and to use combinations of appliances that do not exceed the maximum wattage (amperage) allowed for the house.

The second simulation, Power Controller, stresses concepts relating to the hourly variation in power demand by a medium-size community. A team of three students is responsible for supplying uninterrupted electrical power, at minimum cost, to the community by use of up to four different power sources.

Block I (Energy Sources and Issues) of the New York State curriculum for middle/junior high schools became available as we were well into the explication of software concepts. Happily, the concepts of the two programs fall within the Concepts and Understandings detailed in Block I. They are found, also, in most of the commercial textbooks used by New York State teachers.

Software content goals were easily translated into behavioral objectives. Of greater difficulty was the goal of making the software, and its operation, self explanatory through on-screen text and tutorials. A third goal was to design the programs for game-like operation in the hope of enhancing student enjoyment and learning.

Evaluation procedures

A first round of testing was accomplished in the spring of 1986 in three classes per grade level (6 through 9) at public schools in counties to the north of New York City. Gain scores, affective responses and written comments by the students led to modification of the software. In addition, a six-lesson curriculum package was developed. It

specified pre-simulation and post-simulation reading and homework assignments, hands-on laboratory assignments and audio visual material to be used with the simulation software. Teachers were encouraged to have an extra computer lab period for practice with the software. This suggestion arose from comments by some students that they were not experienced with operation of computers. Also, some needed more time to familiarize themselves with philosophy and operation of the programs.

A second round of testing was accomplished between late fall, 1986, and late spring, 1987. The testing took place in both New York City and suburban public schools. The relatively long testing period was needed so that teachers could integrate the curriculum package into their regular teaching schedule.

The two computer programs and associated curriculum elements were used by a total of 323 students in grades six through nine. Of these, only 292 students completed the pre- and post-test evaluation instruments. Some variation exists in the non-computer elements of curriculum used by individual teachers. Therefore, the number of affective responses is reduced because of procedural and personal factors.

Evaluation results: Watts in a Home

A 22 item, four-choice multiple-choice test was administered both before and after instruction. The sequence of answer choices for each question was changed for the posttest. Table 1 gives the raw data for pretest and posttest scores, by grade and gender, and gain. Pretest scores are above chance expectation for all grade levels. This suggests a fair amount of prior knowledge—especially among students at the three higher grade levels.

A repeated measures analysis of variance was performed on the data. As shown in Table 2 the main effect for improvement from pre- to post-test was statistically significant at the one percent level, as was the interaction between improvement and grade level.

Data on individual student reactions to the program were obtained by use of questions having a five-point Likert response scale. Table 3 presents overall responses relating to the amount of learning resulting from use of the program. Similar data for instructional procedures are given in Table 4. Average responses were positive to very positive for all items on the

opinionnaires. The positive attitudes toward the organization of the software, ease of computer use and working with a partner are especially gratifying in light of the effort expended in hope of achieving such results.

Table 1
Means and Standard Deviations of Pretest, Posttest and Gains
Broken Down by Grade and Gender
Watts in a Home

Grade	Pretest			Posttest			Gains		
	M	F	Total	M	F	Total	M	F	Total
6									
N	20	26	46	20	26	46			
Mean	81	98	90	86	110	100	5	13	9
s.d.	35	24	30	27	28	30			
7									
N	48	72	120	48	72	120			
Mean	108	108	108	106	103	105	-2	-4	-3
s.d.	30	27	28	32	32	32			
8									
N	39	7	46	39	7	46			
Mean	116	110	115	120	136	123	4	26	7
s.d.	30	18	28	28	13	27			
9									
N	32	48	80	32	48	80			
Mean	127	127	127	148	147	147	22	20	21
s.d.	27	24	25	30	32	31			
Total									
N	139	153	292	139	153	292			
Mean	111	112	111	117	120	118	6	8	7
s.d.	33	27	31	36	36	36			

Table 2
Summary of Repeated Measures ANOVA
Of Pretest and Posttest Scores by grade and Sex
Watts in a Home

Source	df	MS	F
Between			
Grade	3	445.8	36.2*
Sex	1	29.8	2.4
Grade x Sex	3	29.2	2.4
Error	284	12.3	
Within			
Score difference	1	100.7	21.8*
Score difference x Grade	3	45.8	10.0*
Score difference x Sex	1	9.6	2.1
Score difference x Sex x Grade	3	5.8	1.3
Error	284	4.6	

*Significant at $p < .01$

Table 3
Student Self-Ratings of Amount of Learning for Each Topic
Of Watts in a Home on a Five-Point Scale^a

Area	N	Mean	s.d.
a. Understanding electrical circuits	281	3.3	1.1
b. How circuit breakers work	280	3.6	1.3
c. Wattage requirements of appliances	280	3.7	1.1
d. Appliance use during day	281	3.9	1.0
e. Computer use	278	3.4	1.4
f. Overall content	281	3.6	1.1

^a 1 = low, 5 = high

Table 4
Student Ratings of Various Aspects of Instruction
In Watts in a Home on a Five-Point Scale^a

Area	N	Mean	s.d.
a. Organization	280	3.7	.9
b. Ease of following	281	3.6	1.0
c. Ease of using computer	280	4.3	.6
d. Fit with regular science instruction	279	3.2	1.1
e. Working with partner (desirability)	276	3.8	1.3
f. Presimulation homework	236	3.2	1.2
g. Postsimulation homework	234	3.1	1.1

^a 1 = low, 5 = high

Evaluation results: Power Controller

A 27 item, four-choice multiple-choice test was administered both before and after instruction. As mentioned previously, the sequence of answer choices for each question was changed for the posttest. Table 5 gives the raw data for pretest and posttest scores, by grade and gender, and gain. Pretest scores are above chance expectation for all grade levels. Again, this suggests a fair amount of prior knowledge- especially among students at the three higher grade levels.

A repeated measures analysis of variance was performed on the data. As shown in Table 6 the main effect for improvement from pre- to post-test was statistically significant at the one percent level, as was the interaction between improvement and grade level.

Data on individual student reactions to the program were obtained by use of a questionnaire having a five-point Likert response scale. Table 7 presents overall responses relating to the amount of learning resulting from use of the program. Average responses were positive for all items. Similar data for instructional procedures are given in Table 8. Average responses were positive to highly positive for all items except those relating to homework assignments. The positive attitudes toward the organization of the software,

ease of computer use and working with a partner are especially gratifying in light of the effort expended in hope of achieving such results. The neutral attitude toward "ease of following" represents a triumph over the earlier test results but suggests that an even greater effort is needed to make this relatively complicated program easier to comprehend.

Table 5
Means and Standard Deviations of Pretest, Posttest and Gains
Broken Down by Grade and Gender
Power Controller

Grade	Pretest			Posttest			Gains		
	M	F	Total	M	F	Total	M	F	Total
6									
	N	20	26	46	20	26	46		
	Mean	9.1	10.7	10.0	10.6	12.4	11.6	1.6	1.7
	s.d.	3.7	3.9	3.9	3.4	5.1	4.5		
7									
	N	48	72	120	48	72	120		
	Mean	12.7	11.8	12.2	16.2	15.6	15.8	3.4	3.8
	s.d.	5.1	4.3	4.6	5.2	4.6	4.8		
8									
	N	39	7	46	39	7	46		
	Mean	14.7	15.6	14.9	18.8	19.6	18.9	4.1	4.0
	s.d.	5.2	5.1	5.2	4.8	4.6	4.7		
9									
	N	32	48	80	32	48	80		
	Mean	15.9	16.4	16.2	21.3	20.9	21.1	5.3	4.5
	s.d.	4.3	4.6	4.5	2.6	3.7	3.3		
Total									
	N	139	153	292	139	153	292		
	Mean	13.5	13.2	13.4	17.3	16.9	17.1	3.8	3.7
	s.d.	5.2	4.9	5.1	5.5	5.4	5.4		

Table 6
Summary of Repeated Measures ANOVA
Of Pretest and Posttest Scores by grade and Sex
Power Controller

Source	df	MS	F
Between			
Grade	3	1380.5	440*
Sex	1	18.71	6
Grade x Sex	3	34.90	1.11
Error	284	31.39	
Within			
Score difference	1	1163.8	131.5*
Score difference x Grade	3	52.5	5.9*
Score difference x Sex	1	.3	.03
Score difference x Sex x Grade	3	3.0	.34
Error	284	8.8	

*Significant at $p < .01$

Table 7
Student Self-Ratings of Amount of Learning for Each Topic
Of Power Controller on a Five-Point Scale^a

Area	N	Mean	s.d.
a. Power demand curve	275	3.2	1.1
b. Power plant operation	275	3.2	1.1
c. Generation costs	274	3.5	1.1
d. Pumped storage	273	3.4	1.1
e. Computer use	270	3.3	1.3
f. Overall content	275	3.5	1.2

^a 1 = low; 5 = high

Table 8
Student Ratings of Various Aspects of Instruction
In Power Controller on a Five-Point Scale^a

Area	N	Mean	s.d.
a. Organization	275	3.5	1.0
b. Ease of following	275	3.0	.9
c. Ease of using computer	275	4.0	.9
d. Fit with regular science instruction	275	3.1	1.1
e. Working with partner (desirability)	275	3.7	1.3
f. Presimulation homework	214 ^b	2.8	1.1
g. Postsimulation homework	220 ^b	2.9	1.1

^a 1 = low; 5 = high

^b A number of students did not receive the homework assignment.

Summary

The two microcomputer simulations about electricity, Watts in a Home and Power Controller, have proved effective and popular when used with an instructional package at the sixth through ninth grade levels. The results for average students should improve with brighter students.

The pretest-posttest results suggest that the programs, while effective at the sixth grade level, will achieve much better results at higher grade levels. There is no question in the writer's mind that adults who are concerned with electrical safety at home and who pay electricity bills also will benefit from exposure to the programs.

Of personal interest to the writer was teacher and student attitude toward group instruction in science using computer simulations. Personal observation and interviews revealed that teachers can overcome difficulties in scheduling computer rooms for science instruction. Also, they easily were able to control a learning situation in which students were very actively conversing with teammates, and other teams, in an effort to develop strategies to achieve good results with the programs.

Of similar interest was the question of student attitude toward cooperating with one or more team members during the learning situation. The

affective data confirm that the team effort is as popular with computer use as it is with well-run laboratory experiences.

Acknowledgments

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**BIBLIOGRAPHY: STUDENTS' ALTERNATIVE FRAMEWORKS
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The bibliography contains some 1000 articles (July 1987). It is being continually updated. The 2nd edition will be available at the end of 1987. Please ask for a copy (address see below). Visitors to the IPN are invited to use the collection of papers on which the bibliography is based. Please help us to keep the bibliography up to date by sending us your papers, articles, etc. You will receive a copy of the bibliography as well as the following edition.

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